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Vibroacoustic Response of Solar Panels: Case Study

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Abstract

Large surface area, lightweight structures, such as solar panels, are easily excited by sound and often experience high acceleration responses during acoustic tests. An accurate prediction of the vibroacoustic response of such structures is critical for design purposes, but is often difficult to achieve, particularly in the case of solar panels in a stacked arrangement. This study investigates the vibroacoustic response of solar panels in various configurations and compares the results to analytical predictions.

Acoustic tests were performed on the panels in several configurations. The test data were evaluated and compared to identify differences in a panel's vibration response for these configurations. In addition, analytical models of the panel were developed using VAPEPS and the response predictions compared to test data to identify areas for potential improvement in the modeling techniques.

Several observations were made from the evaluation of the panel test data and its comparison to VAPEPS predictions. It was determined that the response of the panels is affected significantly by a number of factors, including: panel size, damping, and configuration. Also, VAPEPS predictions were found to be sensitive to the damping parameter, and not very sensitive to other parameters such as stiffness and panel size.

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Vibroacoustic Response of Solar Panels - Case Study

1.0 INTRODUCTION

1.1 Background

Modern spacecraft, such as Magellan, TOPEX, and Mars Observer, commonly employ large solar panels to power their electrical systems. These large surface area, lightweight structures are easily excited by sound and often experience high acceleration responses during spacecraft acoustic tests. An accurate prediction of the vibroacoustic response of such structures is critical for design purposes, but is often difficult to achieve, particularly in the case of solar panels in a stacked arrangement. This study investigates the vibroacoustic response of honeycomb panels in various configurations and compares the results to analytical predictions.

1.2 Objectives

The primary objective of this study is to characterize the vibration response of honeycomb panels in various stacked arrangements representing typical spacecraft solar array configurations. Acoustic tests of the panels were performed in several configurations, including: a single panel simply supported and unbaffled, a single panel in a baffle, and several stacked panels in various combinations. Test data are evaluated and compared to identify differences in a panel's vibration response for these configurations. Analytical models of the panel were developed and the response predictions compared to the test data to identify areas for potential improvement in the modeling techniques. In addition, the models and test data were compared to test data and models from various spacecraft developmental and flight solar panels and arrays.

1.3 Description of Panels

The subject of this study consists of four equal sections of the dynamic mass model (DMM) of the Magellan spacecraft (S/C) solar panel, Figure 1.1. The DMM panel was cut into four equal quarter panels, each with approximate dimensions of 49 inches in width by 49.5 inches in length. Hereafter, each DMM quarter panel is referred to simply as a panel except when it is compared to the original full-size DMM panel. Each panel is made up of .012 inch aluminum face sheets and a .5 inch thick aluminum honeycomb core. One side of each panel is covered by about 256 glass squares (3 x 3 in.) that simulate the mass of the flight panel solar cells.

2.0 VAPEPS ANALYSES

The Vibroacoustic Payload Environment Prediction System (VAPEPS) is used to perform the vibroacoustic analysis of the honeycomb panels. The prediction techniques in the program are based on Statistical Energy Analysis (SEA) theory, which works best in the high-frequency regime where there are a statistically significant number of modes per 1/3 octave frequency band. Good results can generally be obtained for frequencies above the first few panel modes, in terms of frequency-, spatial-, and temporal-averaged vibration responses.

The panel lends itself to SEA due to its simple geometry. However, SEA modeling is not easy. To use the prediction techniques effectively, the analyst must be familiar with the theory and its assumptions, as well as its limitations, particularly in the low-frequency regime.

2.1 Modeling Considerations

2.1.1 Modeling Approach

A simplified model of a single panel was developed from drawings and data of material properties. It consists of a .5 inch thick aluminum honeycomb layer sandwiched by two .012 inch face sheets. Details such as brackets and bolt inserts are not modeled in VAPEPS; however, their mass contribution is added to the model.

2.1.2 Modeling Assumptions

An analyst needs to be aware of the assumptions implicit in using a SEA approach. The following are two of the most important SEA assumptions. First, SEA assumes that the resonant response of a structure is to be modeled, thus its use below the fundamental frequency of the panel is inappropriate. Normally, at least one mode per 1/3 octave band of analysis is required, but three or more modes are preferred to provide confidence in the accuracy of the prediction.

Second, it is assumed that a plate to be modeled is located in an infinite baffle such that sound cannot wrap around the edges. According to theory, this results in more efficient acoustic excitation of the panel and consequently higher panel response accelerations at low frequencies, below the panel critical frequency.

2.1.3 Pre Analyses

The VAPEPS vibroacoustic prediction routine, SEMOD, is applicable only to homogeneous isotropic model elements. Therefore, a multi-layered stiffened panel needs to be converted into a homogeneous flat plate with equivalent properties. The panel layers were smeared into an equivalent homogeneous flat plate using the EQPL processor in VAPEPS. Given the specific dimensions and physical properties of the plate element, the processor calculates a set of equivalent homogeneous parameters (RHO, RHOS, H and E) maintaining the longitudinal wave speed in the material constant. The equivalent parameters for the panel are listed in Table 2.1.

2.2 Description of Panel Model

2.2.1 Breakdown of Panel into SEA Elements

The panel model consists of two basic elements: an equivalent homogeneous plate, PLAT, and an external reverberant acoustic excitation space, EXTA. The VAPEPS model parameters for these two elements are listed in Table 2.1.

2.2.2 Specific Modeling Assumptions (DLF & ASMS)

A scale factor of one (scalefac=1) is used for the panel model predictions. This assumption implies that analytically the model is acoustically excited on one side and that it radiates from only one side. A scale factor of two, for two-sided excitation/radiation, would appear to be the appropriate choice for the model, however, this is not necessarily the case. Using a scale factor of two implies that the acoustic pressure field on opposite sides of the panel is uncorrelated, an assumption that is incorrect for an unbaffled panel at low frequencies, where the acoustic wavelength is greater than a panel dimension. Furthermore, the assumption of one- versus two-sided excitation has little effect (about 1-2 dB) on the response of the panel at frequencies above 300 Hz. Therefore, the best scale factor lies somewhere between one and two, depending on the panel's flight configuration.

The VAPEPS code has five damping function types that can be selected for a particular model, Reference 2.1. The damping function to be used for a model is determined by specifying the damping loss factor (DLF) and pivot frequency (pivotfreq or pvt) parameters and their sign (+ or -) in four possible combinations - the fifth function type involves leaving out the pivotfreq parameter. It should be noted that specifying a negative DLF value is simply a code convention that indicates the particular damping function type to be used, and does not imply that a negative value is used in the analysis.

Figure 2.1 shows a graph of damping function types 1 and 3 that are used in modeling of the solar panel. The damping function selected for the solar panel model corresponds to type 3, and is characterized as follows: a constant damping loss factor value of .01 below 500 Hz, and a value above 500 Hz that varies linearly with frequency by the following equation: $\text{DLF} = 0.01 * 500\ \text{Hz} / f \qquad f > 500\ \text{Hz}$ (pivotfreq=500). The DLF value of .01 was obtained experimentally from damping measurements taken on the panel using the bandwidth method.

A check of the weight of the panel model was made to assure that it matched the actual weight of the panel (16.3 lbs) as measured using a scale. The two weight quantities were made to match by adding an appropriate amount of non structural mass to the model. Non structural mass is defined as component mass that is attached to the panel but does not act to stiffen it. There are two approaches to incorporating this type of mass into a model. The first and most common is to use the ASMS parameter. ASMS reduces the response of the panel model by a factor, M: M= Structural Mass/ (ASMS + Structural Mass). The second approach involves incorporating the mass into the model by modifying the density parameter, RHO. Both methods were tried and no significant difference was found in the response predictions for the panel. The latter approach was used in the final panel model.

2.2.3 General Description of Paths

Path type 49 was used to model the coupling between the plate and the acoustic space element. Path type 49 employs an improved radiation efficiency factor, developed by NASA LeRC, that provides an improved prediction for honeycomb structures below the coincidence frequency.

2.2.4 General description of excitation

The panel model was analytically subjected to acoustic excitation input levels corresponding to the Magellan protoflight (PF) test levels, 146.0 dB OA, Figure 2.2. Sound Pressure Levels (SPL's) are specified in 1/3 octave bands from 25 to 2500 Hz.

2.3 Response Predictions for Panel Model

A summary of the external acoustic space excitation and average response predictions for the panel model are listed in Table 2.2. A maximum response value of 5.52 g^2/Hz occurred at a center frequency of 100 Hz. A plot of the average and 95th %-tile response spectra for the panel is shown in Figure 2.3. VAPEPS calculates the 95th %-tile response by adding a factor of 7.4 dB to the predicted mean response. This factor is based on a VAPEPS default value of 4.1 for the ratio of the variance to the mean-square response, σ^2/m^2.

A parametric study of the model was performed to evaluate the effect of damping (DLF's) and stiffness (E) on the response prediction for the panel. The response predictions for the model with various values of damping are compared in Figure 2.4. The comparison shows that the response prediction is sensitive at low frequencies to the DLF's used in the model. Also, for the simple two element model the response prediction of the panel was unaffected by changing the value of E. It appears that VAPEPS does not use the parameter E directly, but instead calculates its value from other element parameters ($E=C_L^2*RHO$).

3.0 PANEL ACOUSTIC TESTS

Testing of the honeycomb panels was performed in the 10,000 cubic foot reverberant acoustic chamber (22 x 18 x 26 ft) in the Environmental Lab at JPL. Test operations and data acquisition were performed by the Environmental Lab personnel.

3.1 Test Configurations

The panels were tested in the following configurations: 1) unbaffled panel, 2) baffled panel, and 3) stacked panels in several arrangements. The test sequence and run descriptions are listed in Table 3.1. All panel configurations were tested to the Magellan PF acoustic levels, Figure 2.2.

3.1.1 Single Panel - Unbaffled

A single panel was tested in an unbaffled configuration by suspending it from steel cables near the center of the acoustic chamber. The panel was oriented so that it was not parallel to any of the chamber walls to avoid setting up any standing waves. The panel was instrumented with eight accelerometers at various locations to obtain a good spatial average response, Figure 3.1. Two control microphones were used as input to the digital control system that was used to control the acoustic levels in the chamber during the tests. The control microphones were located on either side of the panel about 22 inches from its surface. Also, three additional microphones were placed 1-2 inches from the panel surface to measure the near-field SPL's. A single test run (# 2) was completed for this configuration.

3.1.2 Single Panel - Baffled

A large plywood frame, 1/4 inch thick, was built to serve as a baffle. The baffle resembles a matted picture frame with a large opening in the middle, see Figure 3.2. Its dimensions are 14 feet in height by 18 feet in length with about a 4 foot square opening in the middle. The opening is large enough so that placement of the panel in the baffle leaves about a 1 inch gap all around the edges. The area around the opening is reinforced by four foot wide sections of 3/4 inch thick plywood. The baffle is held upright by a rectangular support structure of wooden beams.

The panel was centered in the frame opening and anchored with duct tape so that the panel edges did not touch the plywood and thus prevent a mechanical connection between the two structures. The baffle and panel combination was then positioned across the chamber at an angle to the walls. Instrumentation of the baffled panel remained the same as for the unbaffled panel. Two test runs (# 3 & 4) were completed for this configuration. The only difference between the two runs is that the near-field microphones were shifted to different positions.

3.1.3 Several Panels - Stacked

The panels were assembled into different stack configurations by using PVC tubing standoffs and four long bolts, one at each corner, as illustrated in Figures 3.3-3.5. An inner and an outer panel was each instrumented with four accelerometers, and with three microphones located between the panels to measure the interior SPL's, Figures 3.3-3.5. The interior microphones were enclosed in soft foam rectangles to keep them from contacting the panels. In addition, two external microphones were placed on either side of the panel stack to control the acoustic excitation levels. A total of nine test runs (# 5-13) was completed for the panels in various stack arrangements, Table 3.1.

3.2 Data Reduction and Analysis

Microphone and accelerometer data were recorded on a 14-channel tape recorder. The response data was digitized into narrow band (5 Hz) power spectral density (PSD) values from 25 to 2,500 Hz, and then reduced to 1/3 octave band PSD values. Plots of the response data, narrow and one-third octave band, and the measured SPL's for all test runs are listed in Appendix A.

The actual SPL's to which each panel configuration was exposed, as measured by the two control microphones, differed somewhat for all test runs and from the specified Magellan PF levels, Figure 3.6. Therefore, the response data for each run were normalized to the Magellan PF SPL's by using the corresponding SPL measurements for each run. The normalized data are used in all subsequent comparisons and evaluations in this report. Response data from each test run were averaged for comparison with the VAPEPS model predictions.

3.3 Panel Damping Measurements

The damping in a system is indicated by the width of the response curve at a resonant frequency. It is approximated as the ratio of the bandwidth at the half power point divided by the resonant frequency : $DLF = \Delta f/f_n$. The procedure utilized was to measure the response of the panel to transient excitation (i.e. tapping on the panel) using an accelerometer at various panel locations. The data was captured and analyzed using a spectrum analyzer that yielded the necessary natural frequencies and corresponding bandwidths to estimate the damping in the panel. The damping values for the panel, measured at several locations, are plotted in Figure 3.7. A DLF of .01 was obtained by drawing a straight line through the data, that roughly approximates the average of the data. The natural frequencies of the panel that were excited during the above procedure are listed in Table 3.2. An attempt was made to excite as many of the panel modes as possible by taking measurements at various panel locations, as well as by tapping the panel at different places during each measurement. A set of plots of panel modal responses are listed in Appendix B.

4.0 EVALUATION

4.1 Model Validity

The fundamental mode of the panel occurs at 24.5 Hz. In theory, the panel model is applicable above this frequency, however, valid predictions are only obtained when enough modes are present in the frequency band of analysis. Normally, at least three modes per 1/3 octave band are required to allow for predictions with an acceptable degree of certainty (Fewer modes means larger dispersion in magnitudes). VAPEPS calculates for the panel model a constant modal density value of .03 modes/Hz for the entire frequency range. That means that the model has a mode roughly every 33 Hz, and will have less than one mode per 1/3 octave band at frequencies below 145 Hz. It will have three modes or more per 1/3 octave band at frequencies above 435 Hz. The number of panel modes is calculated as follows: # modes = .23 $* F_c * n$, where n is the modal density and F_c is the center frequency of the 1/3 octave band of interest.

The actual resonant modes of the panel, as noted during the damping measurement procedure, Table 3.2, differ significantly from those of the VAPEPS model. The actual modes of the panel are not evenly spaced and have significant gaps in the frequency spectrum where no modes are present, see Appendix B. The modal gaps are mirrored by valleys in the vibration response data.

4.2 Comparison of DMM Full-Size Panel and 1/4 Panel - Unbaffled

The Magellan DMM panel was previously tested at JPL, Reference 4.1, before being cut into four quarter panels for the present study. An evaluation is made henceforth of the vibration response differences between the full-size DMM panel (8 x 8 ft.) and a quarter section of the DMM panel (4 x 4 ft.). The spatial average vibration response of the full-size panel is compared to that of the 1/4 panel in Figure 4.1. The response of the two panels is similar above 400 Hz, but is very different below that frequency. The response of the full-size panel is about 9 dB higher than the 1/4 panel between 40-100 Hz, and 3-6 dB higher between 125-315 Hz. Both panels are essentially identical except for their surface area, and so the difference in their response is due to the difference in their size.

The size of a panel determines its modal density, an important parameter in the response of a panel, and affects its characteristic modal behavior, particularly at low frequencies. As discussed previously, the 1/4 panel showed significant modal gaps in the frequency spectrum (50-65, 65-125, etc.). The same dips can be seen to a lesser degree in the data for the full-size panel. The modal density is proportional to surface area, and so the full-size panel has a modal density roughly four times that of the 1/4 panel. Thus, the response difference between the panels is due primarily to the difference in their modal density. Also, individual modes (i.e., corner modes, edge modes, etc.) play an important role in the response of the panel at low frequencies. The effect of these modes needs to be evaluated considering the above results.

4.3 Comparison of DMM Panel Responses to Magellan, TOPEX and MO Panels S/C Test Responses

Vibration response data from the DMM panel is compared to solar panel data from the Magellan, Mars Observer and TOPEX S/C system acoustic tests in Figure 4.2. The DMM panel was used in the Magellan S/C system acoustic test. The Magellan, MO and TOPEX S/C data used in the comparison, along with the test SPL's and diagrams showing the location of the accelerometers for each of the solar panels, are listed in Appendices C , D and E respectively. Data from the four tests were normalized to Magellan PF acoustic levels for the comparison. The structural dimensions of the panels are listed for the three spacecraft in Table 4.1. All three solar panels are of honeycomb construction with very large surface areas.

The response of the DMM panel in the S/C configuration is about 3 dB lower than the response for the single DMM panel except between 70-100 Hz where it is slightly higher. The response of the DMM panel also compares fairly well, within ~3 dB, with that of the TOPEX solar panel. However, the responses of the three panels diverge at the low and high frequencies. It should be noted that each panel was tested in a different configuration. The Magellan DMM panel was tested alone, without a support structure, and in a S/C configuration, whereas, both the TOPEX and MO solar panels were tested in a launch configuration. The MO data used in the comparison represents the response of the external panel of a six-panel stacked array. Likewise, the TOPEX data represents the response of the external panel of a four-panel stacked array. The differences in the response of the panels are due primarily to the physical and test configuration differences between the panels.

4.4 Comparison of Unbaffled and Baffled Panels

The Magellan DMM panel was previously tested to investigate the effects of a baffled versus an unbaffled configuration on its vibration response. According to theory, the radiation efficiency and response of a baffled panel are higher, at low frequencies, than for an unbaffled panel. Test data on the DMM panel did not strongly reflect the expected theoretical effect on the panel's vibration response, Figure 4.3. It was thus decided to test a 1/4 panel in a similar configuration to verify the previous results obtained for the full-size DMM panel.

The average vibration response of the unbaffled 1/4 panel is compared to that of the baffled 1/4 panel in Figure 4.4. The response of the baffled panel is about 3-10 dB higher than that of the unbaffled panel from 25-125 Hz, and about 1-3 dB lower above 250 Hz. The effect of the baffle on the 1/4 panel's response was significantly more pronounced than on the full-size panel. This result was not unexpected as the larger panel is to some degree baffled due to its size. Also, the plywood baffle used in tests of the 1/4 panel was considerably more rigid then when used for the full-size panel, since thicker plywood was used to reinforce it. This also may have contributed to the increased baffle effect on the response of the 1/4 panel.

The response of both the large and small baffled panels deviated from theory above 100 Hz, where it was lower than the response of an unbaffled panel. It was expected that the response of the baffled panel would be higher, not lower, than that of the unbaffled panel below its critical frequency of 667 Hz, and similar above that frequency. The decrease in the response of the baffled panels above 100 Hz is likely due to increased damping of the panel by the tape used to hold it in the baffle. An ideal baffle would have very rigid boundaries and would be mechanically disconnected from the panel so as not to impart or draw energy to/from the panel. In practice, it is difficult to achieve these conditions. The above comparison shows that the response of a panel in a baffle, as compared to the response of an unbaffled panel, tends to increase at frequencies below 100 Hz, and may decrease above 100 Hz.

4.5 Evaluation of Stacked Panels

4.5.1 Comparison of Single Panel to Panel in a Stack

The average vibration response of an outside panel in various stacked configurations is compared to the response of a single unbaffled panel in Figure 4.5. The vibration response of the panel in a stack is slightly lower than that of the single panel below 200 Hz, about equal above 400 Hz, but significantly higher by 3-6 dB between 300-400 Hz. The SPL's measured between the panels were 5-10 dB higher between 200-400 Hz than those measured by the control microphones, see Appendix A. However, the increase in the internal SPL's was not due to a standing acoustic wave forming between the panels since a wavelength equal to the 2 inch gap would have a resonant frequency of 6,600 Hz, which is beyond the frequency range where the increase in SPL's is occurring. The first resonant mode of the air space between the panels was calculated, using the equation below, to determine if it coincided with the frequency at which the internal SPL's were highest.

$$f_n = \frac{c}{2}\left[\left(\frac{n_x}{L_x}\right)^2 + \left(\frac{n_y}{L_y}\right)^2 + \left(\frac{n_z}{L_z}\right)^2\right]^{\frac{1}{2}}$$

This equation gives the natural frequencies for an acoustic space of dimensions L_x, L_y, and L_z, where c is the speed of sound in air and n_x, n_y, n_z can be any combination of integers. The first resonant mode (0,1,0) of the air space (2 inch gap) occurs at 133 Hz which is about 1/2 the frequency of interest. A rational explanation for this phenomenon has not been found.

4.5.2 Comparison of Interior to Exterior Panel

The average response differences (delta, dB) between the exterior and interior panel for all configurations are compared in Figure 4.6. On average the response of the exterior panel is generally higher than the response of the interior panel by 3 to 4 dB. This result is intuitively appealing since the inner panels would appear to be acoustically shielded by the outer panels. However, that notion runs contrary to the fact that higher SPL's were measured between the panels, and so it would be reasonable to expect the interior panel to have a higher vibration response. One possible explanation is that the interior panels, rather than being acoustically driven, are mechanically driven by the outer panels through the bolt attachments. This explanation needs to be evaluated in more detail.

4.5.3 Other Observations

The average vibration response of the outer panels are compared for the various configurations. No significant difference in panel response was found between a 3- and a 4 panel configuration, Figure 4.7. However, the panels stacked with a one inch gap separation exhibited response levels 1-3 dB lower than the panels stacked with a two inch gap, Figure 4.8.

4.6 Comparison of VAPEPS Predictions to Test Data

4.6.1 Comparison to Unbaffled Panels

The VAPEPS average response prediction is compared to the spatial average response of the test data for the unbaffled full-size and quarter panels in Figure 4.9. Clearly, VAPEPS significantly over predicts the 1/4 panel data below its critical frequency of 700 Hz, and slightly under predicts (less than 2 dB) above this frequency. The over prediction is particularly glaring between 40-125 Hz and between 125-200 Hz, where it differs from the data by more than 15 dB. Data from the full-size panel compares somewhat more favorably with the prediction. This result was surprising as VAPEPS had previously been shown to provide acceptable response predictions for honeycomb type structures, References 4.2-4.5. There are, however, several mitigating factors that help explain the discrepancy between the prediction and the data. These factors include, but are not limited to, the effects of damping, modal density, and a baffle configuration. These factors are discussed briefly in the following sections.

4.6.2 Evaluation of Damping

Damping is one of the most difficult parameters to determine for a system. It is important to estimate the values of damping accurately since SEA models are very sensitive to this parameter, Figure 2.4. VAPEPS has been used in the past to model honeycomb type structures with a varying degree of success, References 4.2-4.5. Models using high values of damping, DLF = .05 to .10, were found to yield response predictions which more closely agreed with data. To illustrate the effect of damping, the response prediction of a TOPEX S/C solar panel model is compared to data from the S/C system acoustic test in Figure 4.10. A DLF value of 0.10 was used for the model. The prediction agrees with the data between 130-200 Hz, but overpredicts below 130 Hz by about 3-4 dB and underpredicts above 200 Hz by 1-6 dB. Also, the response prediction of an MO solar panel model is compared to data from its S/C system acoustic test in Figure 4.11. A much lower DLF value of 0.018 was used for this model. In this case, the prediction is conservative across the spectrum, particularly so at frequencies below 100 Hz.

High damping values may be justified for complex structures where a substantial degree of damping is introduced into the system through friction between component parts, joints, and other mechanisms. However, with a simple system like a bare honeycomb panel, loaded with glass squares, those types of damping mechanisms may not be present. Even though the measured damping represents only an approximation of the true system damping, it was decided to use the measured values of damping in the model. As a result, the VAPEPS prediction is extremely conservative when compared to the test data. Applying higher damping values to the model results in a prediction that compares more favorably with the data, Figure 4.12. VAPEPS models are so sensitive to the DLF's used, that it is possible to closely approximate the data by tuning these values, particularly at low frequencies.

4.6.3 Evaluation of Modal Density

VAPEPS provides the best predictions for structures with high modal density. The prediction schemes yield very conservative predictions at low frequencies where there are few modes. The effect of low modal density needs to be considered when comparing the panel's prediction to the data. As was discussed previously, the fact that the panel exhibits gaps in the frequency spectrum where no modes are present, affects the validity of the prediction, which is based on an even distribution of modes across the spectrum. As an example, the response data from the full-size DMM panel, with its high modal density, showed a much closer agreement to the VAPEPS model response predictions than did the response data from the 1/4 panel, Figure 4.12. This points out an important fact, that VAPEPS only predicts a structure's spatial average response and not its response peaks or valleys. Also, the role of individual modes becomes important at low frequencies and their effect on the response of the panel needs to be investigated. Furthermore, it should be noted that a direct comparison between the response prediction and the response of the unbaffled panel is inappropriate since VAPEPS predicts the response of a baffled panel. The effects of a baffle are discussed in the following section.

4.6.4 Comparison to Baffled Panel

It is more appropriate to compare the VAPEPS response prediction to response data from the panels in the baffled configuration. The prediction compares somewhat more favorably with data from the baffled full-size and quarter panels, Figure 4.13.

VAPEPS predicts the response of the panels in a baffle within ~3 dB above its critical frequency, but is still highly conservative in the mid- to low-frequencies. As discussed previously, the agreement between the prediction and the data would be better if higher DLF's had been used in the panel models.

4.6.5 Comparison to Stacked Panels

The VAPEPS response prediction is compared to test data from the exterior panel in various stack configurations, Figure 4.14. The prediction agrees well with the data at a frequency of 315 Hz and above, but severely overpredicts below this frequency. The agreement at 315 Hz is of interest because the SPL's measured between the panels at this frequency were significantly higher than those measured by the control microphones. The panel is driven, either mechanically or acoustically, to very high response levels at this frequency. It is unclear whether this behavior is specific to the particular setup used in tests of the panels, or is shared by all stacked panels. The physical mechanism driving the panel at this frequency is not yet understood.

5.0 CONCLUSIONS

5.1 Summary

Several interesting observations were made from the evaluation of the panel test data and its comparison to VAPEPS predictions. It was determined that the response of the panels is affected significantly by a number of factors, including: panel size, damping, and configuration. However, although VAPEPS predictions were found to be quite sensitive to the damping parameter, they are not very sensitive to other parameters such as stiffness and panel size. Following is a brief summary of the effect of these factors on the response of the panels.

It has been shown that modal density has a big effect on the response of honeycomb panels at low frequencies. As a result of its size, the response of the full-size DMM panel was significantly higher than that of the 1/4 panel below 400 Hz. VAPEPS assumes an even modal distribution for a panel across the spectrum and consequently does not account for the changes in modal density observed at low frequencies in the real panel structures. The VAPEPS prediction was found to be relatively insensitive to panel size as it predicted similar responses for the full-size panel and 1/4 panel.

The response of a structure is very dependent on its damping. Likewise, VAPEPS predictions were found to be very sensitive to the damping parameter. Unfortunately, the damping in a system is difficult to determine accurately. A comparison of the MO, TOPEX, and Magellan panel model predictions to test data showed that those models using higher values of damping achieved better agreement between the prediction and the data. It is possible to get good agreement between a prediction and data by adjusting the values of damping in the model. It is suggested that future models of solar panels take advantage of available data by performing extrapolation predictions for those models.

The average response of a panel was also found to vary significantly between configurations. Comparison of the response of baffled and unbaffled panels showed that the response of a baffled panel was ~1-3 dB higher below 100 Hz and ~2-3 dB lower above 100 Hz. The increase in response at low frequencies was more pronounced on the 1/4 panel than on the full-size panel as would be expected. It is believed that the decrease in the response of the baffled panel above 100 Hz is due to additional damping introduced by the tape used to hold the panels in the baffle.

The response of a panel in a stack was found to be 3-6 dB higher than that of a single panel between 200-400 Hz. The SPL's measured between the panels at those frequencies were 5-10 dB higher than those measured by the control microphones. A rational explanation for the mechanism driving these panels at 200-400 Hz has not been found. Also, the response of an exterior panel in a stack was generally higher than that of an interior panel, and the response of panels stacked 1 inch apart were ~1-3 dB lower than those stacked 2 inches apart.

5.2 Follow-on Work

It has been shown that modal density plays a key role in the vibroacoustic response of a panel. The response of the full-size DMM panel was very different from that of the smaller 1/4 panel below the critical frequency. However, the VAPEPS predictions for the two panels are almost indistinguishable. As part of an outgrowth of this task, a study is planned to develop techniques using FEM modal information in VAPEPS to improve its low frequency prediction capability.

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4.3 McNelis, Mark E., A Modified VAPEPS Method for Predicting Vibroacoustic Response of Unreinforced Mass Loaded Honeycomb Panels, NASA Technical Memorandum 101467, May 1989.

4.4 T. Scharton, TOPEX/Poseidon Spacecraft Acoustic Test Results, JPL IOM 5216-92-058, April 23, 1992.

4.5 Badilla, G., "Mars Observer Solar Array Vibroacoustic Response Prediction," JPL IOM 5216-92-034, April 13, 1992.

6.1 O'Connell M. R., "Mars Observer Sine Vibration, Acoustic Noise and Pyrofiring Results," JPL IOM 5216-92-081, May 27, 1992.

6.2 Park, D. M., VAPEPS Users Reference Manual, Version 5.1, NASA Contractor Report 180781, May 1990.

6.3 R. H. Lyon, "Statistical Energy Analysis of Dynamical Systems: Theory and Applications," MIT Press, 1975.

6.4 Y. A. Lee, D. Crowe, W. Henricks, "VAPEPS Improvement with Stress Estimation and Progressive Wave Excitation", Lockheed Missiles and Space Company, NASA Contract Report 180783, June 1987.

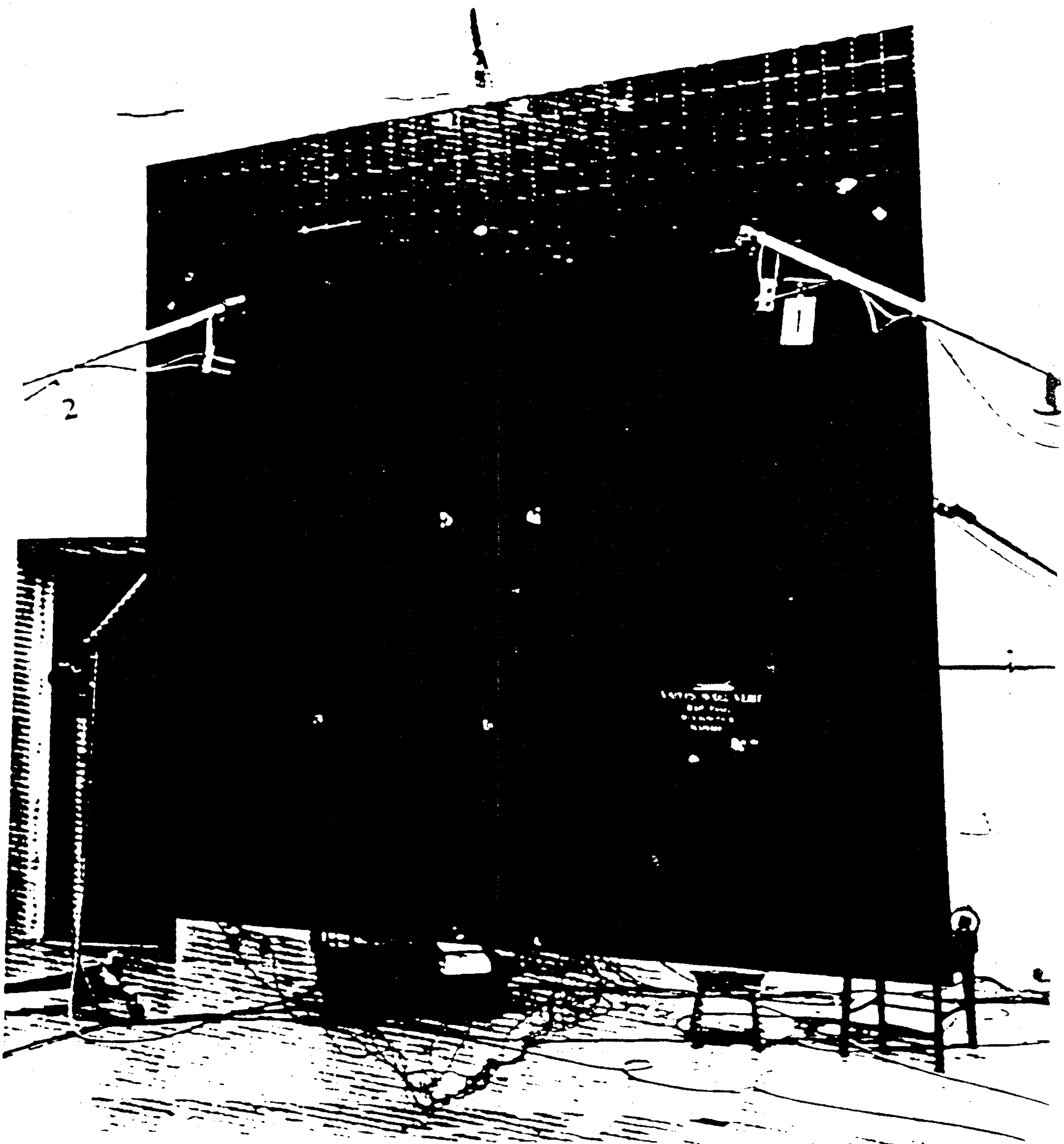


Figure 1.1 - Magellan Spacecraft Solar Panel, Dynamic Mass Model

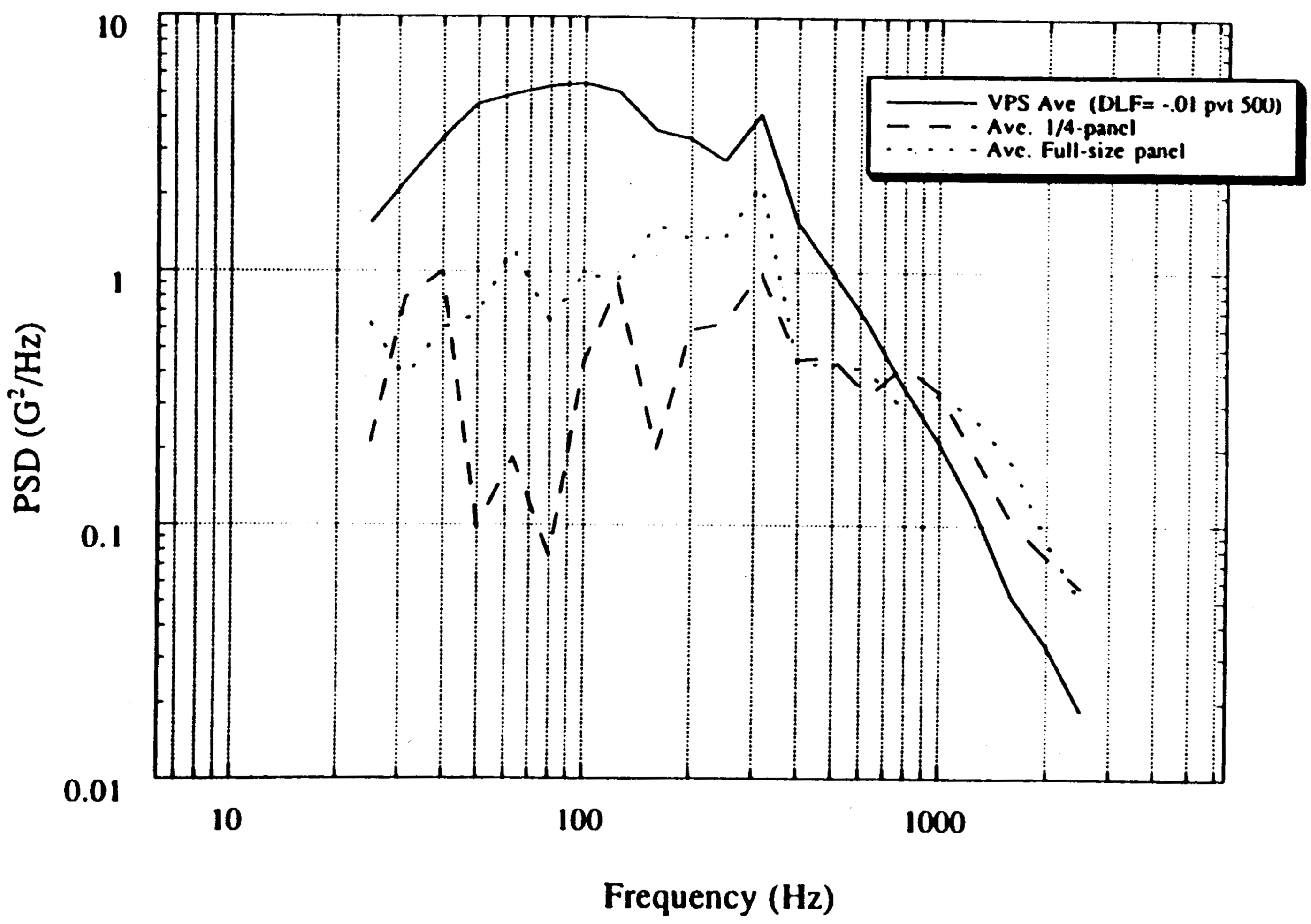


Figure 4.9 - Comparison of VAPEPS Prediction and Acoustic Data for Full Size & 1/4 Panels (unbaffled)

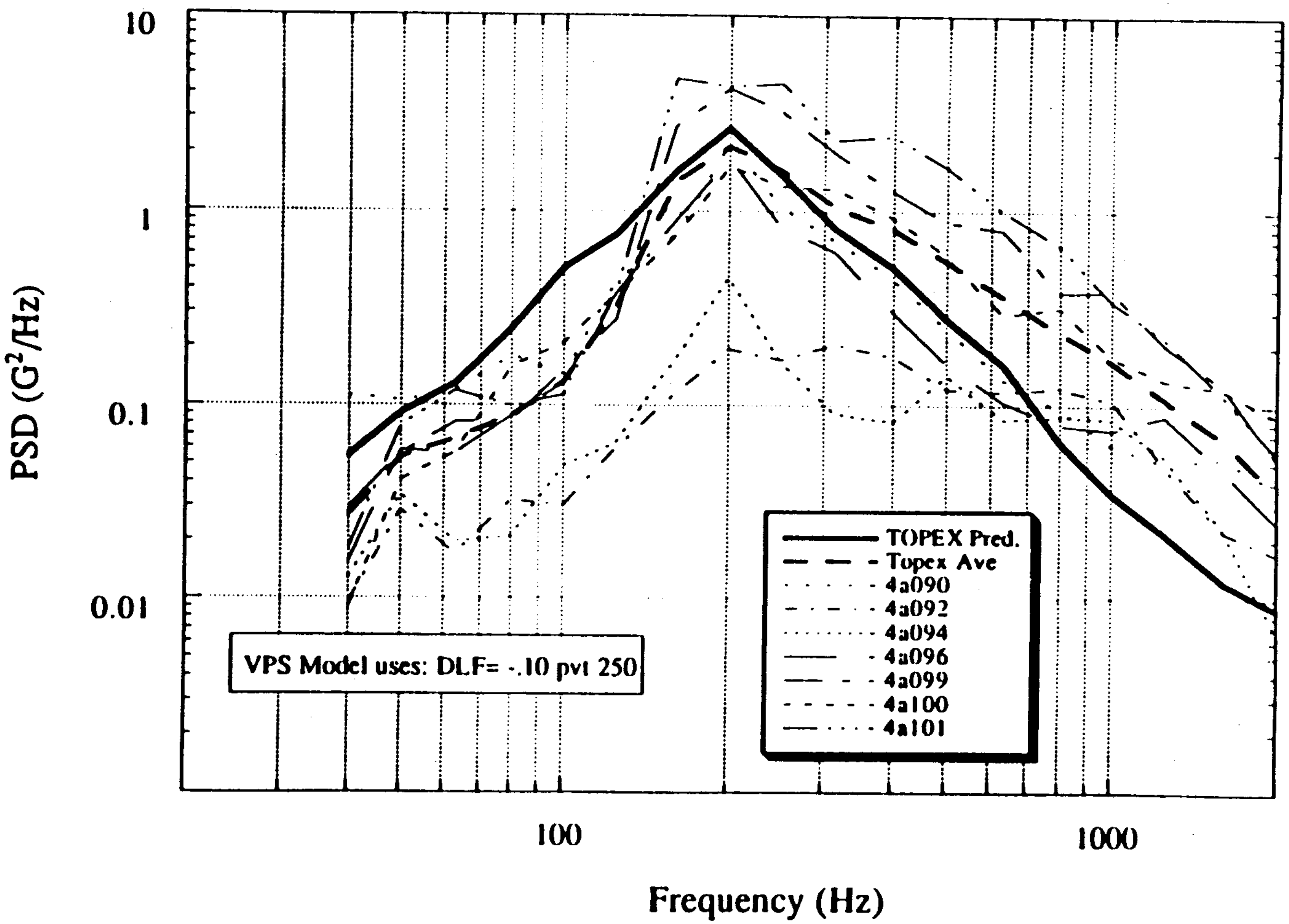


Figure 4.10 - Comparison of VAPEPS Prediction and Acoustic Data for TOPEX Spacecraft

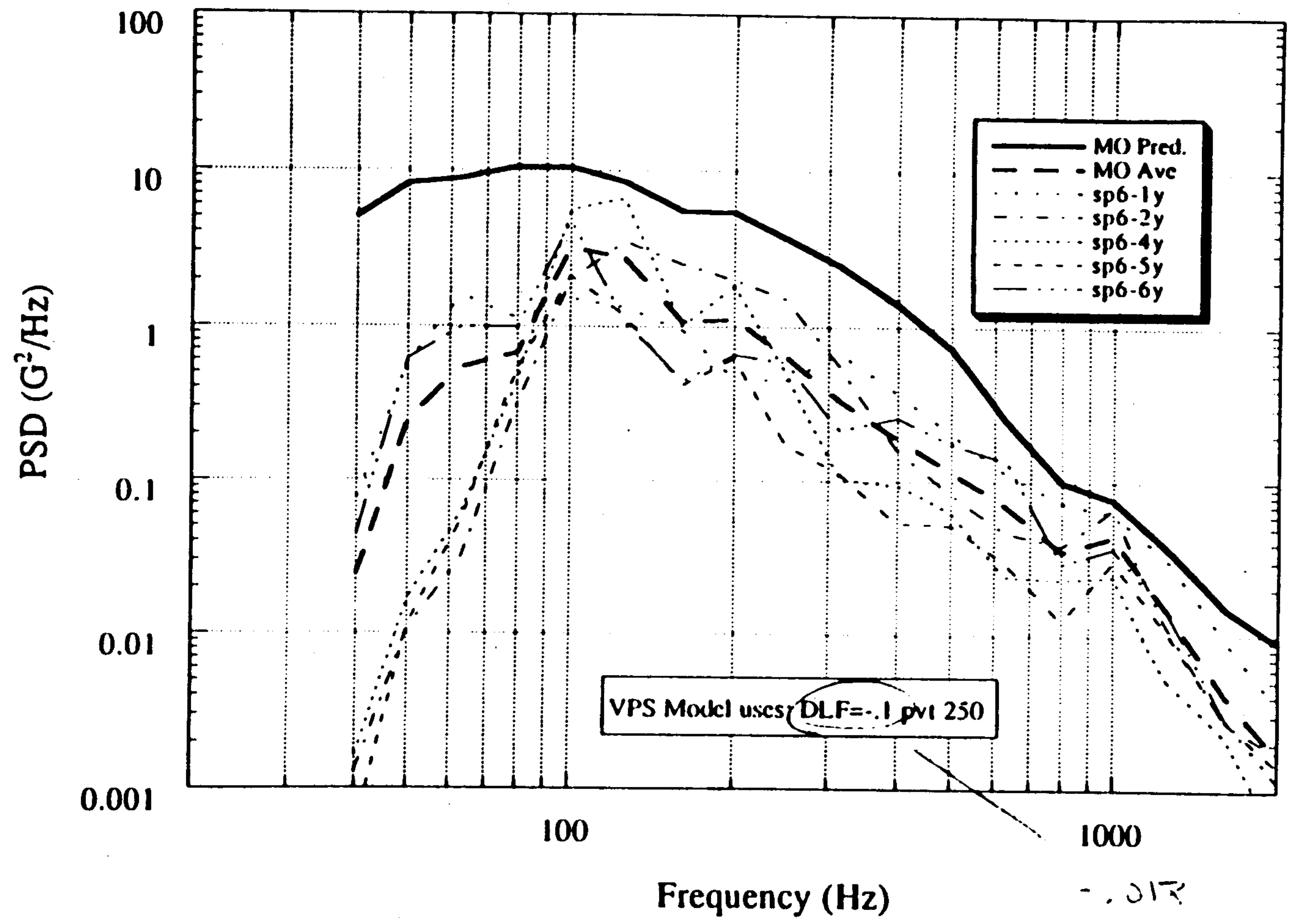


Figure 4.11 - Comparison of VAPEPS Prediction and Acoustic Data for MO Spacecraft

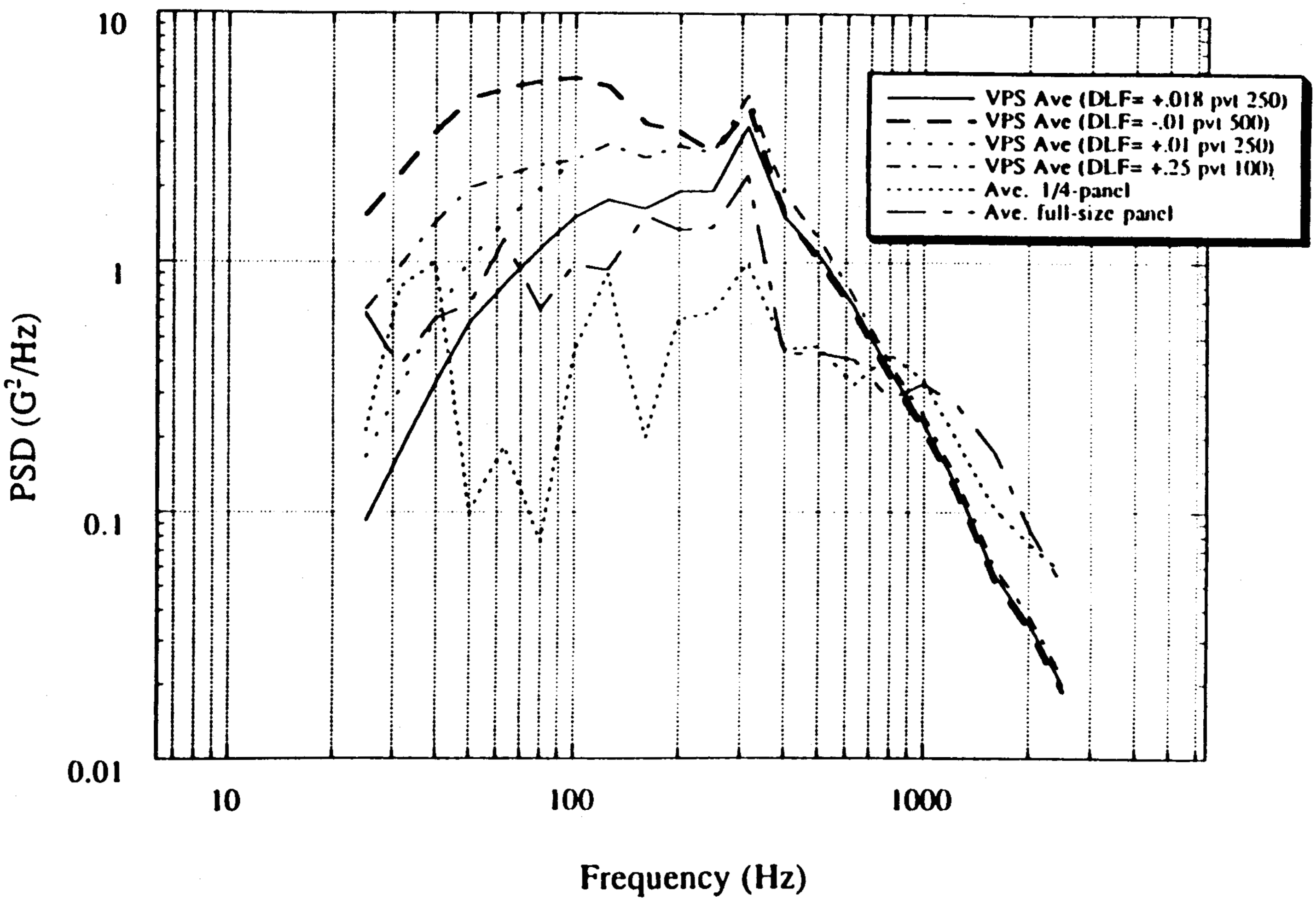


Figure 4.12 - VAPEPS Predictions for Various DLF's Compared to Acoustic Data for Full Size & 1/4 Panels (unbaffled)

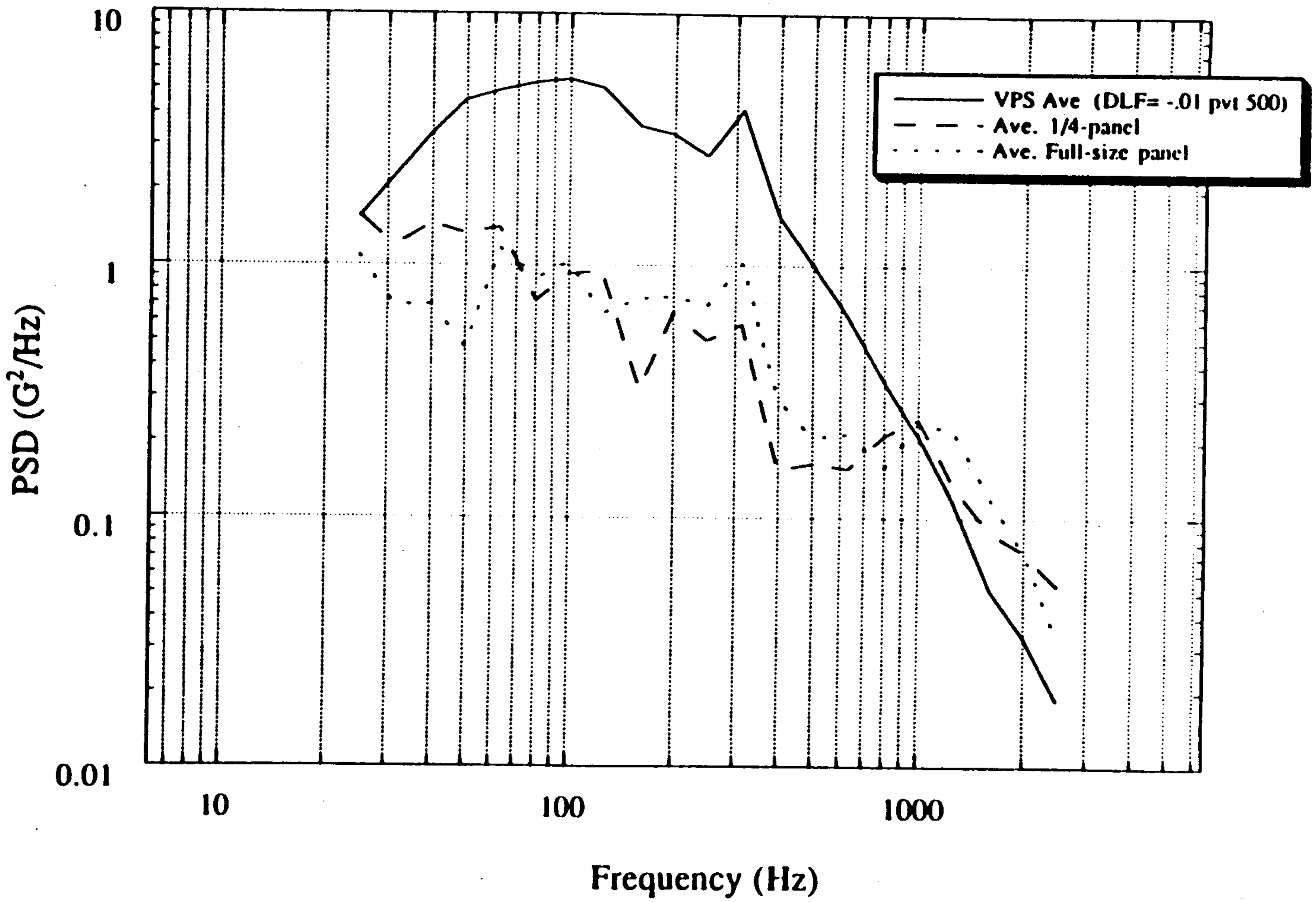


Figure 4.13 - Comparison of VAPEPS Prediction and Acoustic Data for Full Size & 1/4 Panels (baffled)

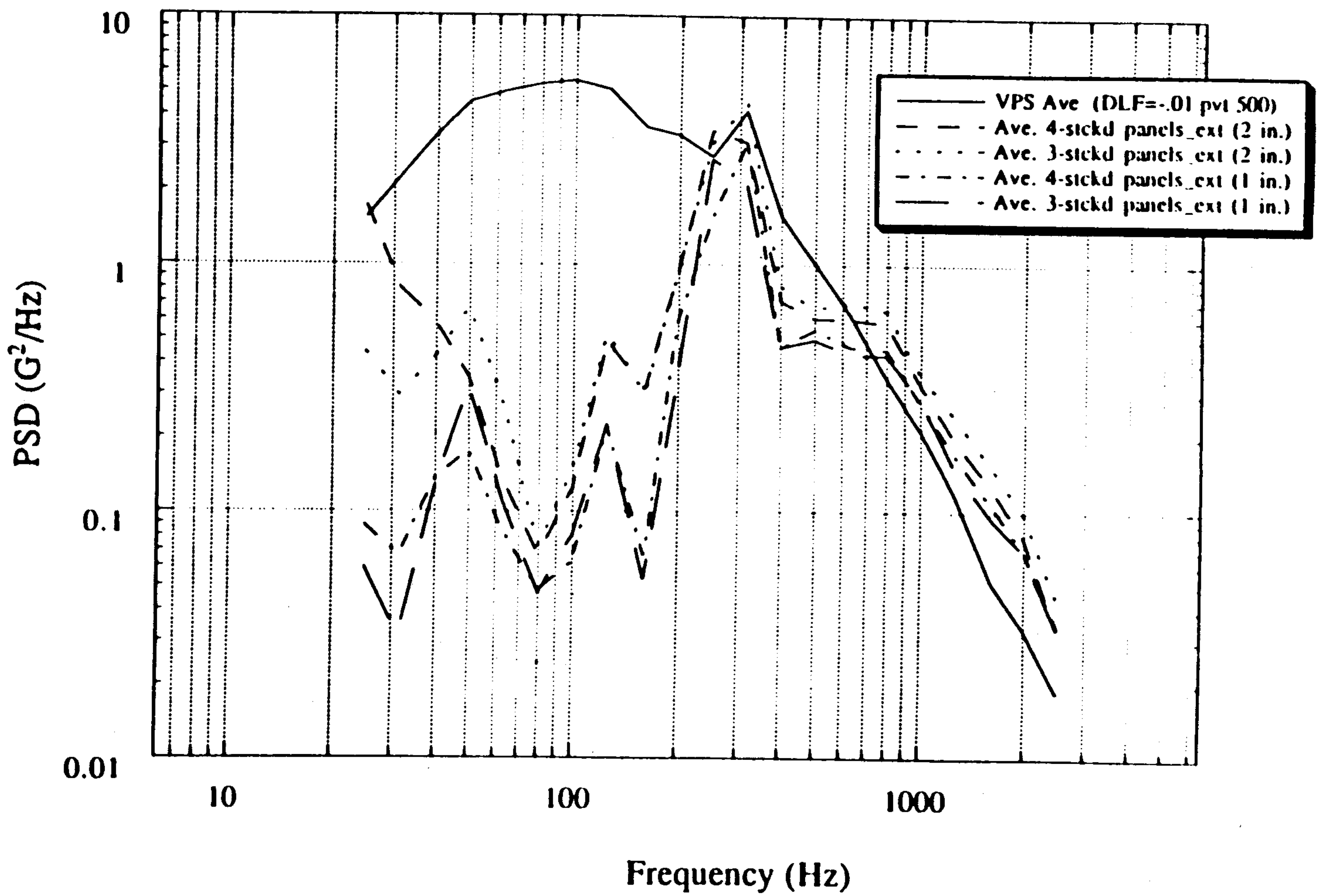
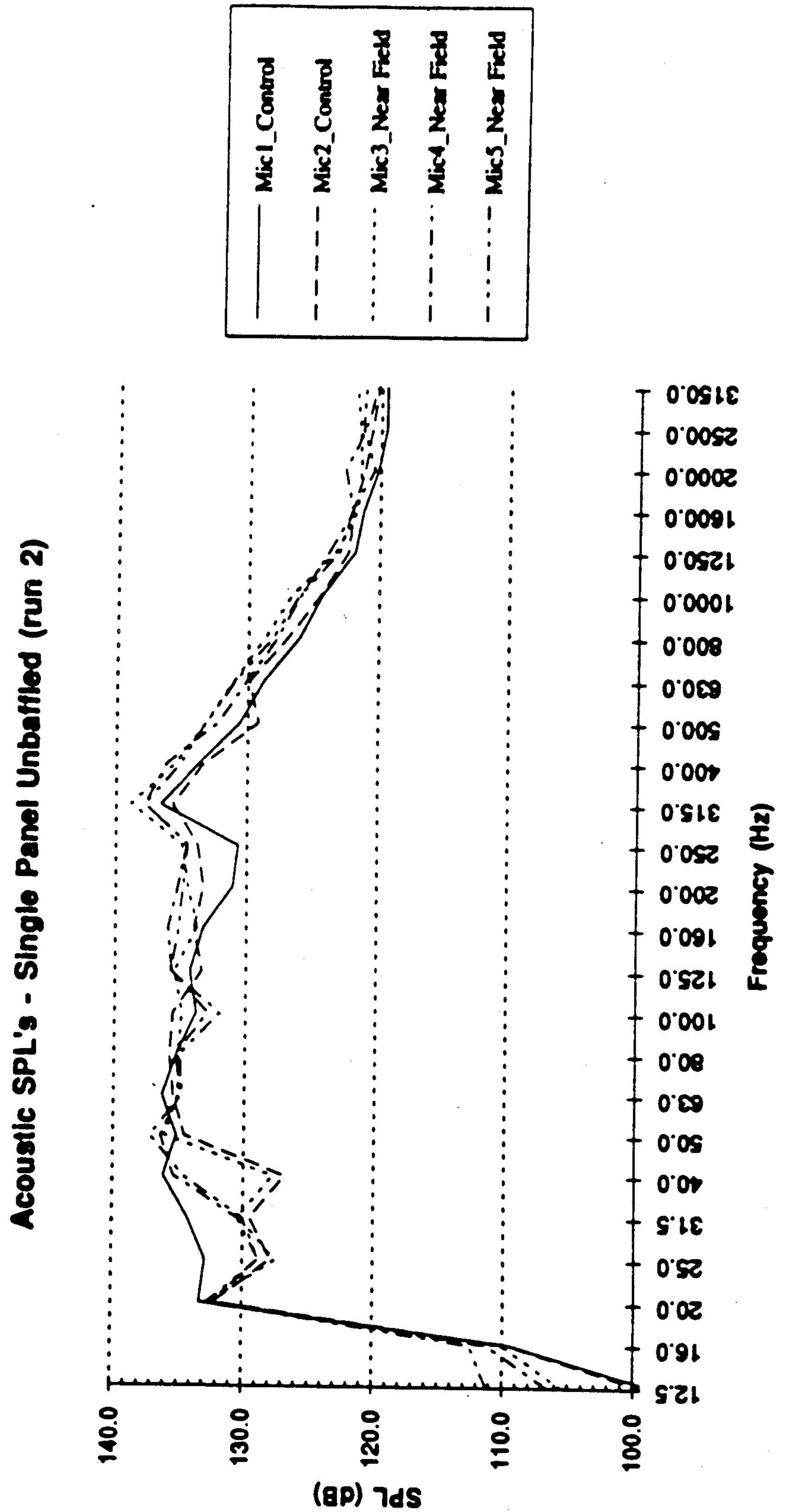


Figure 4.14 - Comparison of VAPEPS Prediction and Acoustic Data for 1/4-Panels in Various Stack Configurations

Appendix A:

Honeycomb Panels - Acoustic Test Data
(SPL's, Narrow & 1/3 Octave Band Data)


Acoustic SPL's - Single Panel Unbaffled (run 2)
Mic1_Control
Mic2_Control
Mic3_Near Field
Mic4_Near Field
Mic5_Near Field
SPL (dB)
140.0
130.0
120.0
110.0
100.0
Frequency (Hz)
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0

Parameter	Acoustic Space	Plate
CO - Speed of sound in air (in/sec^2)	1.31E+04	n/a
Volume - Volume of Space	1.73E+07	n/a
AAC - Acoustic Absoprtion Coefficient	0.01	n/a
AP - Surface Area (in^2)	4.13E+05	2.44E+03
RHO - Mass Density (sec^2-lbs/in^2)	n/a	2.45E-05
H - Thickness (in.)	n/a	0.7009
E - Young's Modulus of Elasticity (lbs/in^2)	n/a	6.18E+05
CL - Bending Wave Speed (sec/in)	n/a	2.01E+05
ALX - Typical Sub-panel dimension (in.)	n/a	49.1
ALY - Typical Sub-panel dimension (in.)	n/a	49.6
DLF - Damping Loss Factor	n/a	-0.01
PATA - Edge Discontinuity Length (in.)	n/a	0
ASMS - Non-structural Mass (lbs-sec^2/in)	n/a	0

Table 2.1 - 1/4-Panel VAPEPS Model Parameters

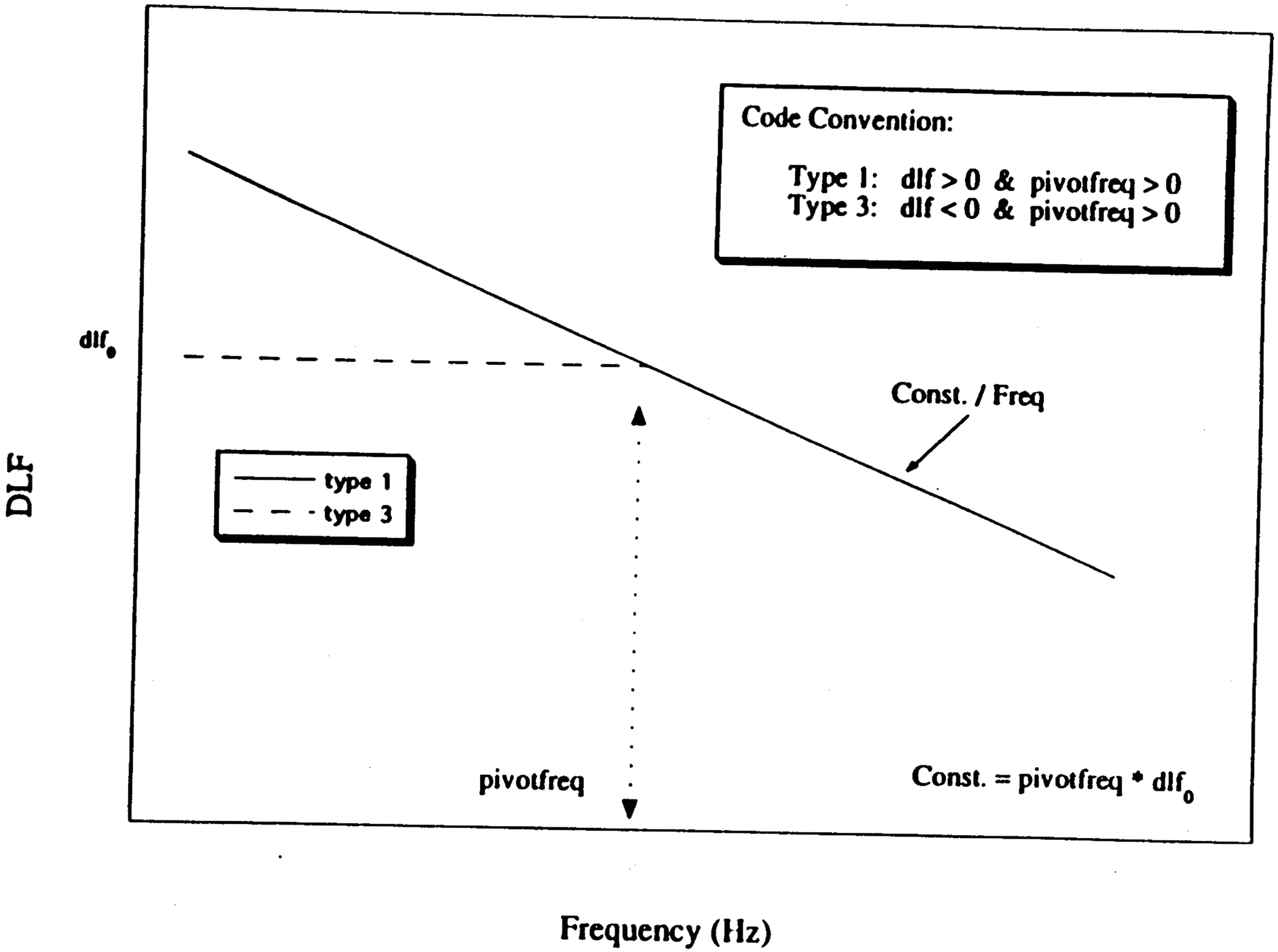


Figure 2.1 - VAPEPS Damping Function Types (5 available)

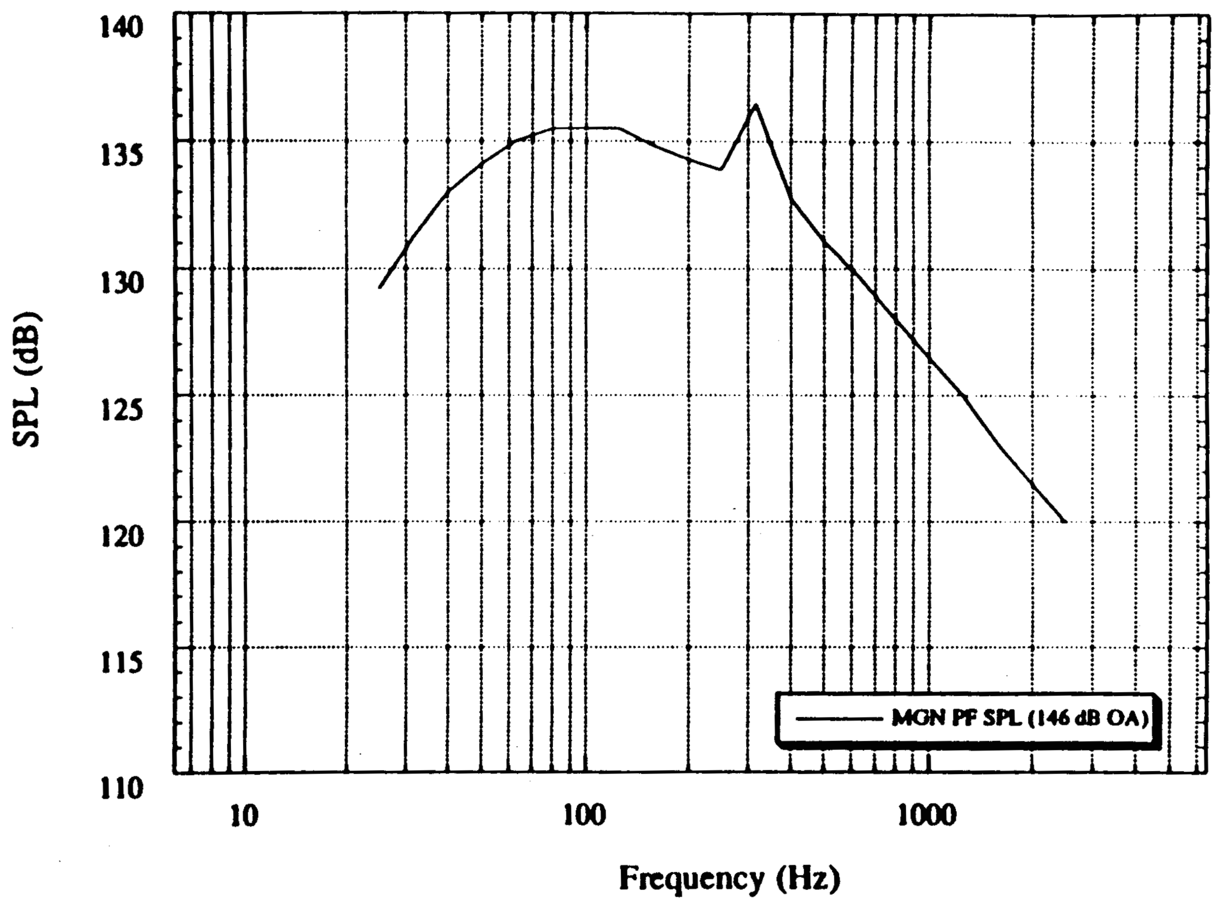


Figure 2.2 - Magellan Protoflight Acoustic Sound Pressure Levels

Frequency	SPL's	Average	95%-tile
(Hz)	(dB)	(g^2/Hz)	(g^2/Hz)
25.0	129.2	1.55	8.98
31.5	131.2	2.27	13.10
40.0	133.0	3.36	19.50
50.0	134.1	4.54	26.30
63.0	135.0	4.99	28.90
80.0	135.5	5.37	31.10
100.0	135.5	5.52	31.90
125.0	135.5	5.11	29.60
160.0	134.8	3.61	20.90
200.0	134.3	3.37	19.50
250.0	133.9	2.75	15.90
315.0	136.5	4.22	24.50
400.0	132.8	1.59	9.22
500.0	131.1	1.02	5.90
630.0	129.7	0.63	3.66
800.0	128.0	0.35	2.01
1000.0	126.5	0.21	1.23
1250.0	125.0	0.12	0.69
1600.0	123.0	0.05	0.30
2000.0	121.5	0.03	0.20
Overall (grms)	146.0	43.0	103.0

Table 2.2 - 1/4 Panel Model SPL's and Response Predictions

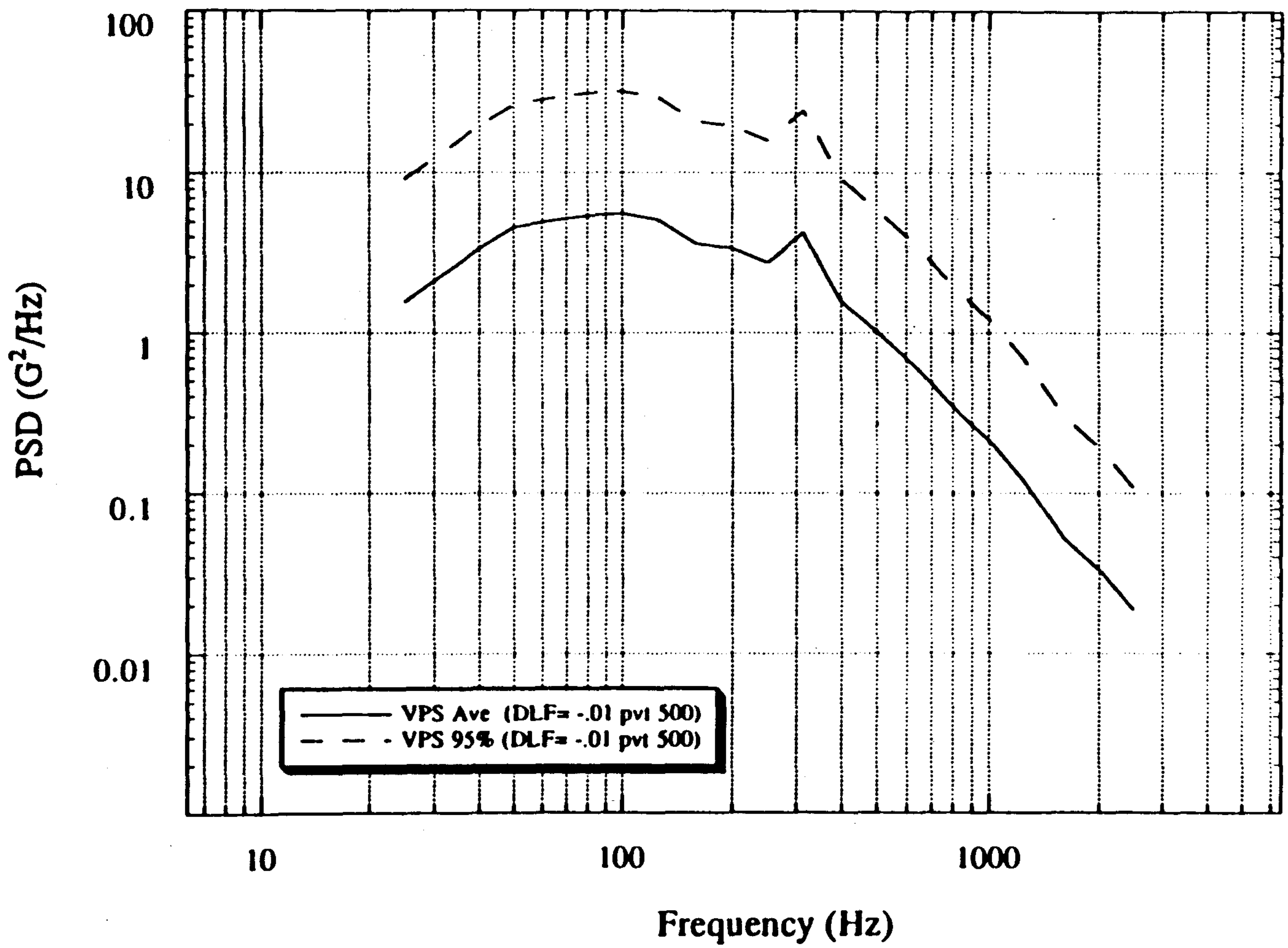


Figure 2.3 - 1/4 Panel Model VAPEPS Response Predictions

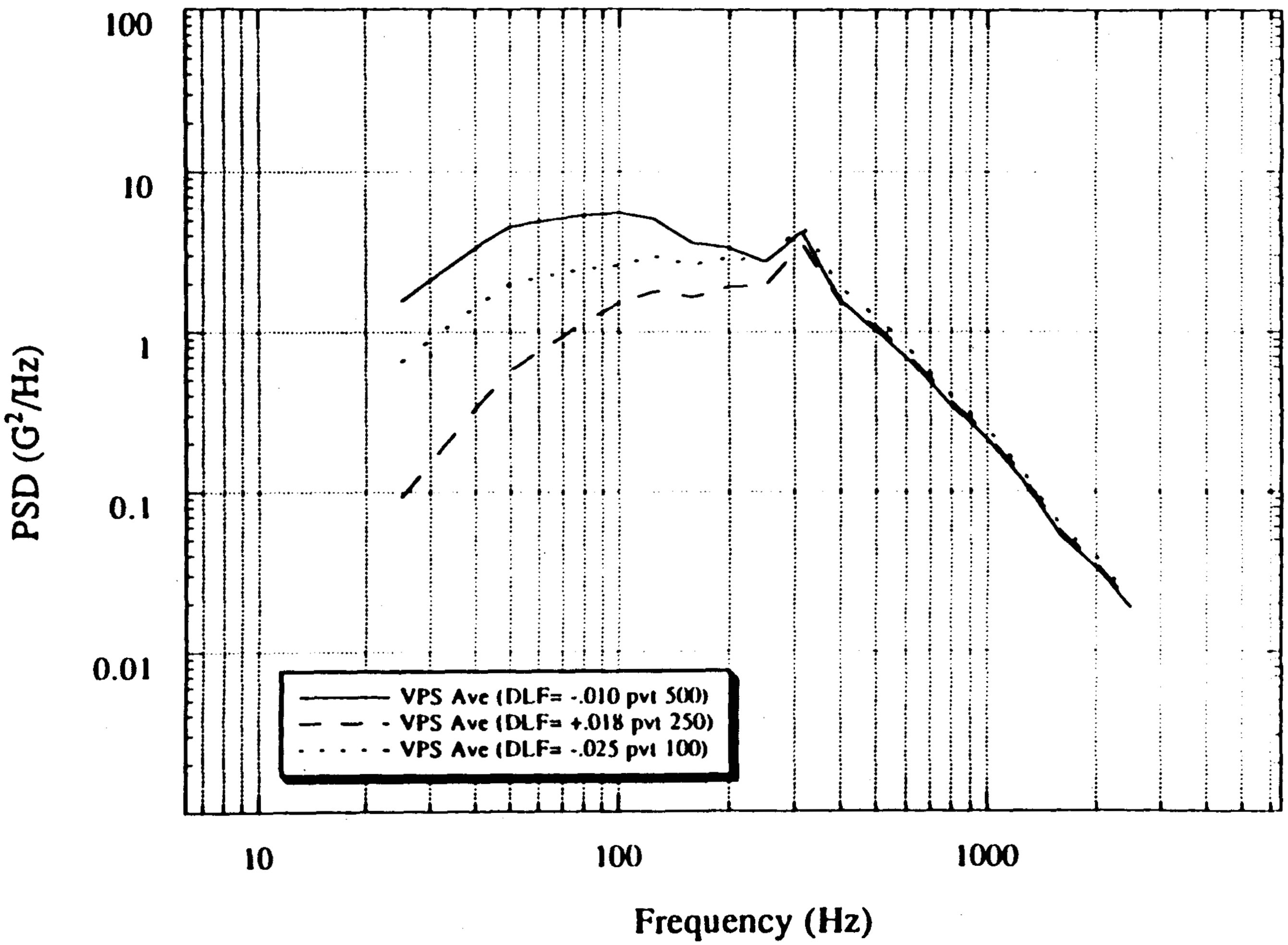
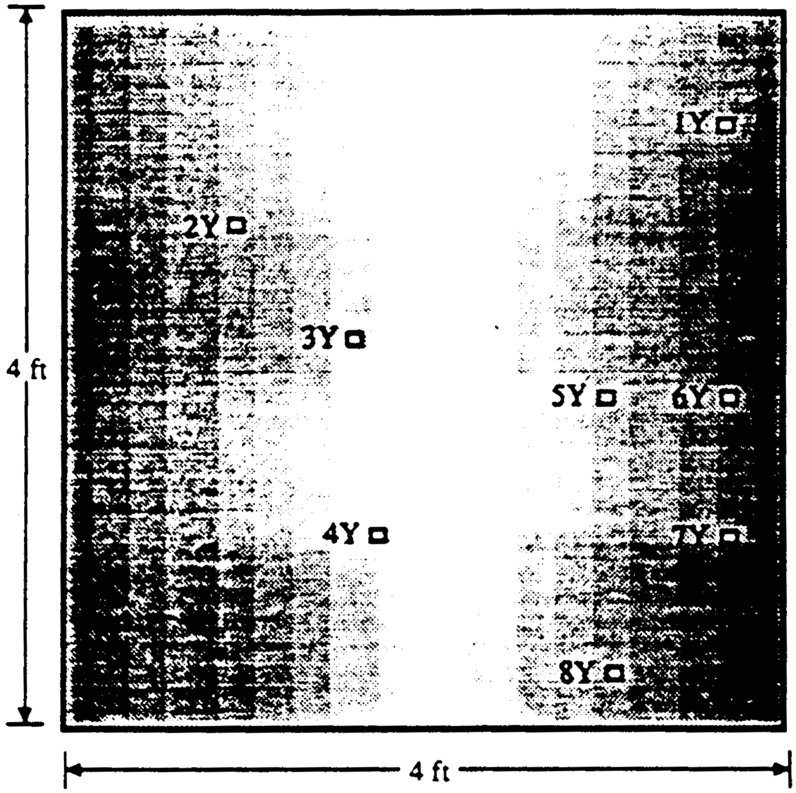


Figure 2.4 - 1/4 Panel Model VAPEPS Response Predictions for various DLF's

Run No.	No. of Panels	Description
1	Single Panel	Bad Run
2	Single Panel	Unbaffled, suspended from ceiling by bungee cord
3	Single Panel	Baffled, taped to plywood baffle
4	Single Panel	same; changed position of near-field microphones
5	4-Panels	Panels stacked 2 inches apart
6	4-Panels	same; changed position of near-field microphones
7	4-Panels	same; changed position of near-field microphones
8	3-Panels	Panels stacked 2 inches apart
9	3-Panels	same; changed position of near-field microphones
10	4-Panels	Panels stacked 1 inch apart
11	4-Panels	same; changed position of near-field microphones
12	3-Panels	Panels stacked 1 inch apart
13	2-Panels	Two sets of panels stacked 1 & 2 inches apart, respectively

Table 3.1 - Acoustic Tests of 1/4-Panels; Sequence and Description

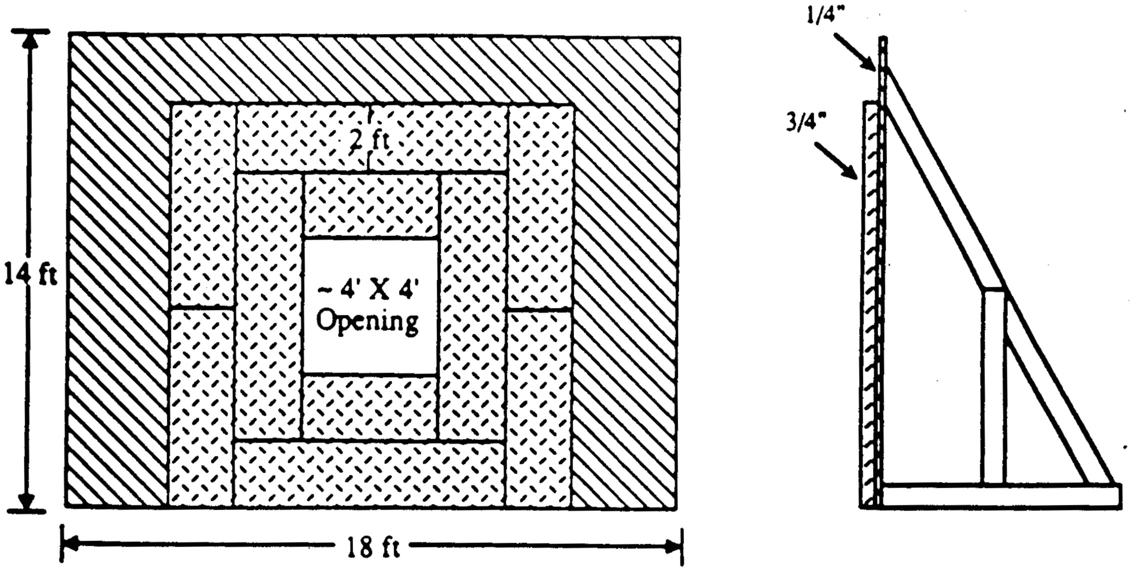


Instrumented with:

(Not to Scale)

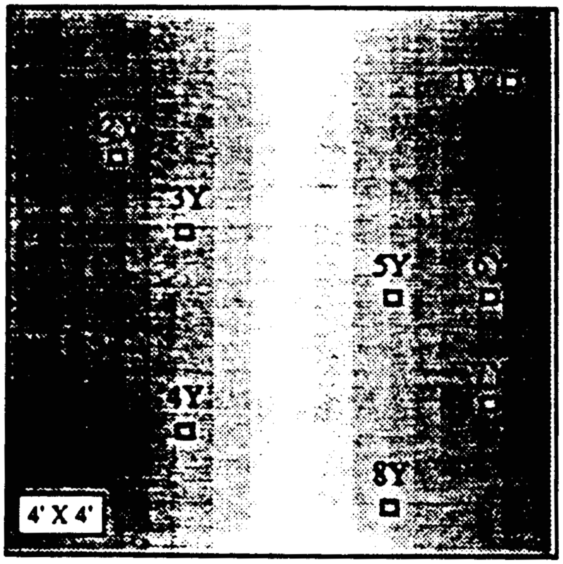
8 Accelerometers,
2 Control Microphones
3 Near-field Microphones

Figure 3.1 - Unbaffled Panel Configuration



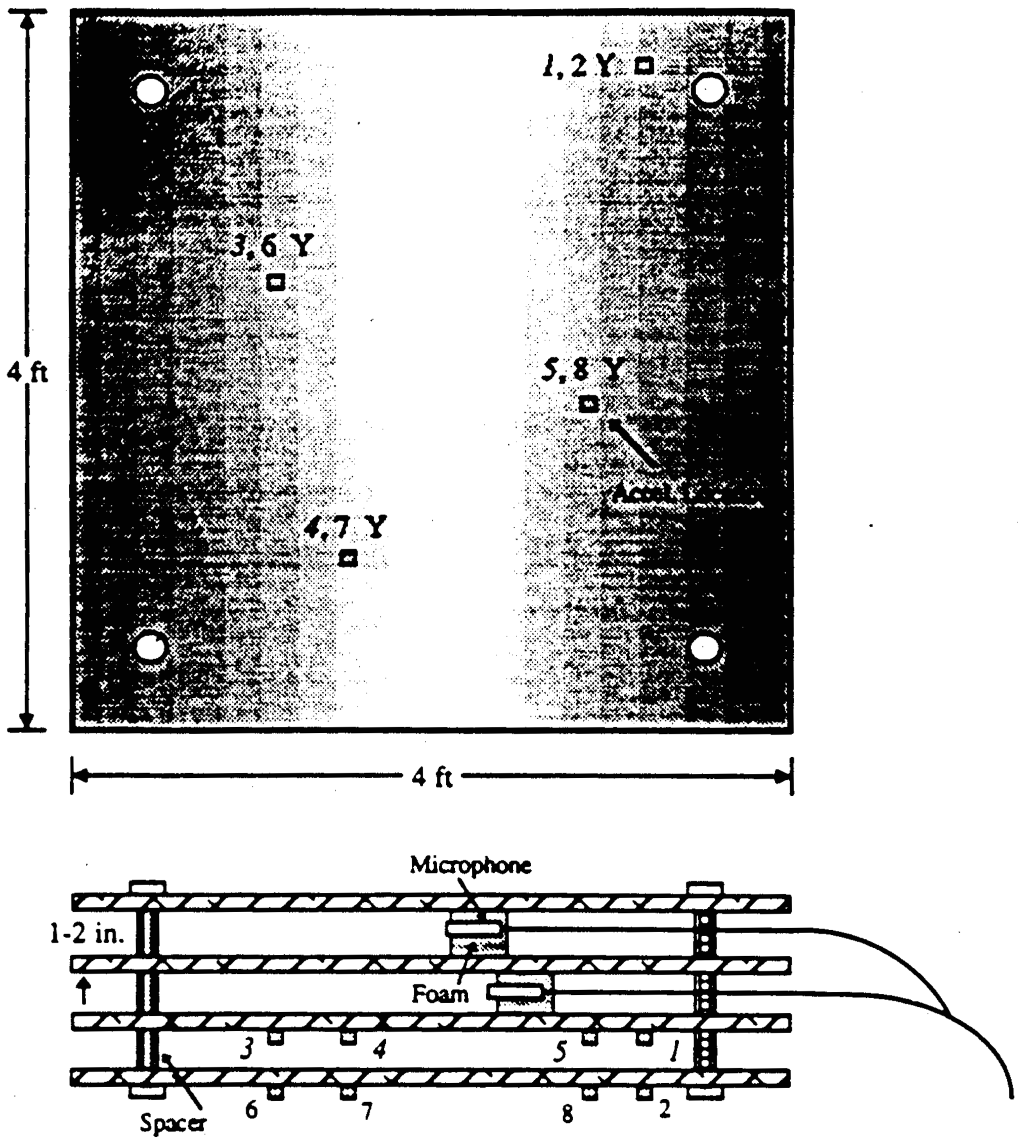
(Baffle Front View)

(Baffle Side View)



(Not to Scale)

Figure 3.2 - Baffled Panel Configuration

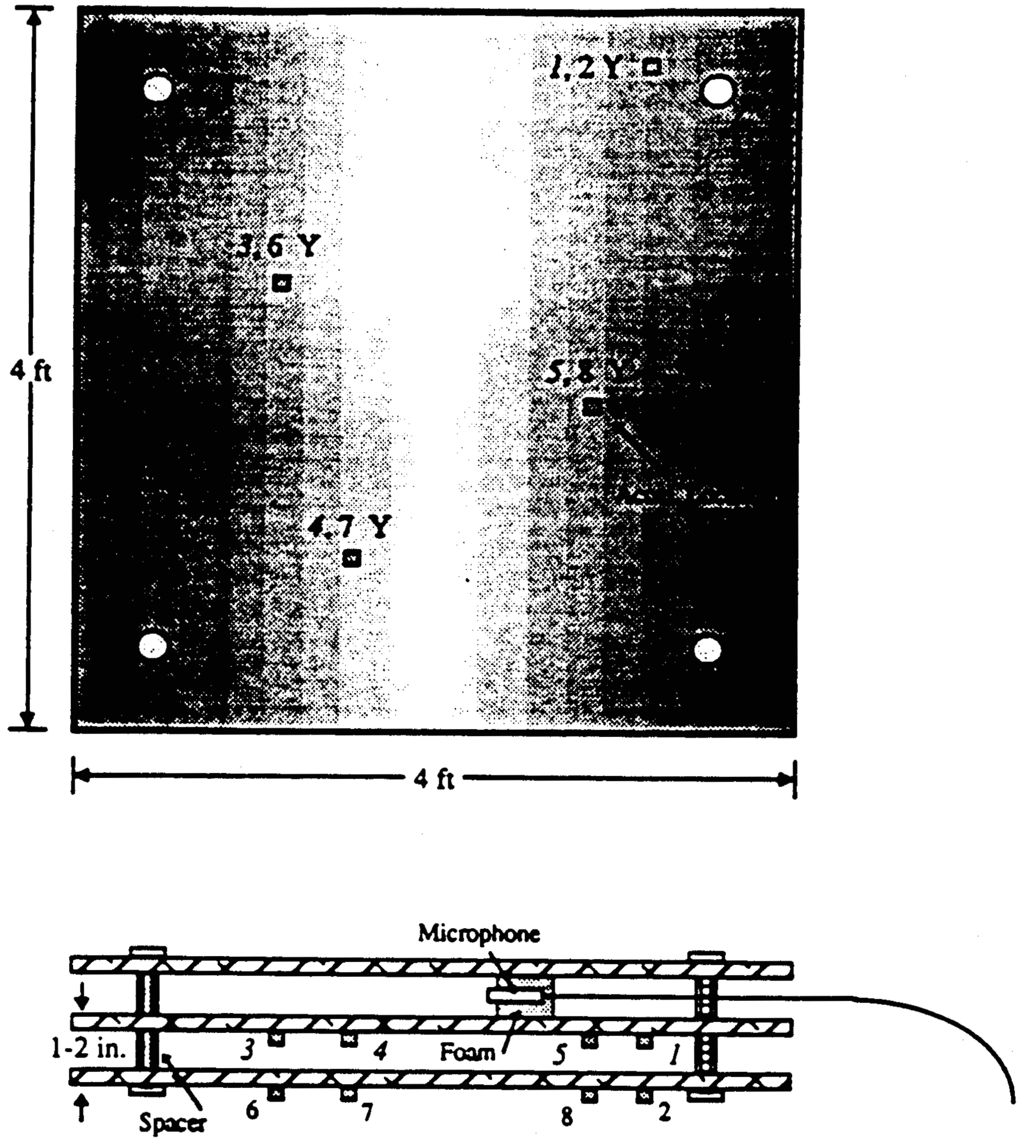


Instrumented with:

8 Accelerometers,
2 Control Microphones
3 Near-field Microphones

(Not to Scale)

Figure 3.3 - Four Panels Stacked Configuration

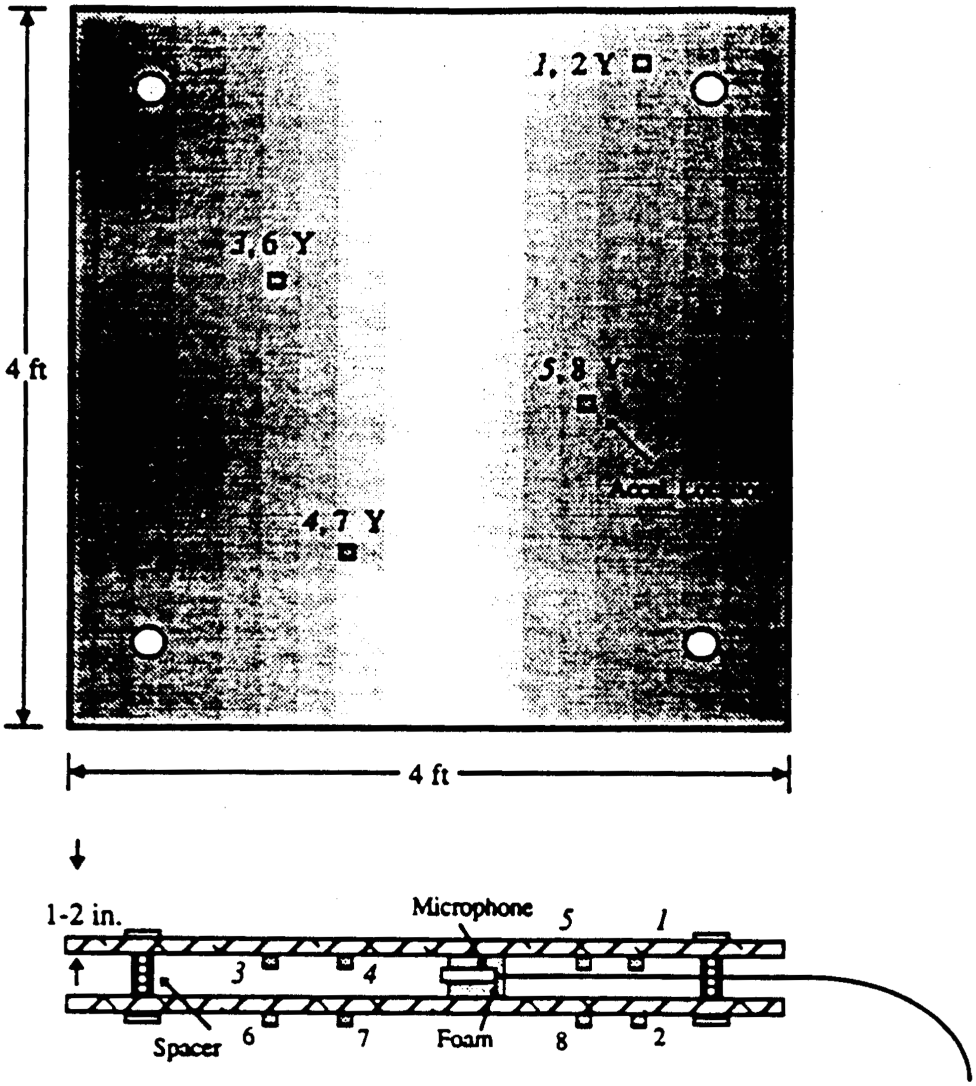


Instrumented with:

8 Accelerometers,
2 Control Microphones
3 Near-field Microphones

(Not to Scale)

Figure 3.4 - Three Panels Stacked Configuration



Instrumented with:

(Not to Scale)

8 Accelerometers,
2 Control Microphones
3 Near-field Microphones

Figure 3.5 - Two Panels Stacked Configuration

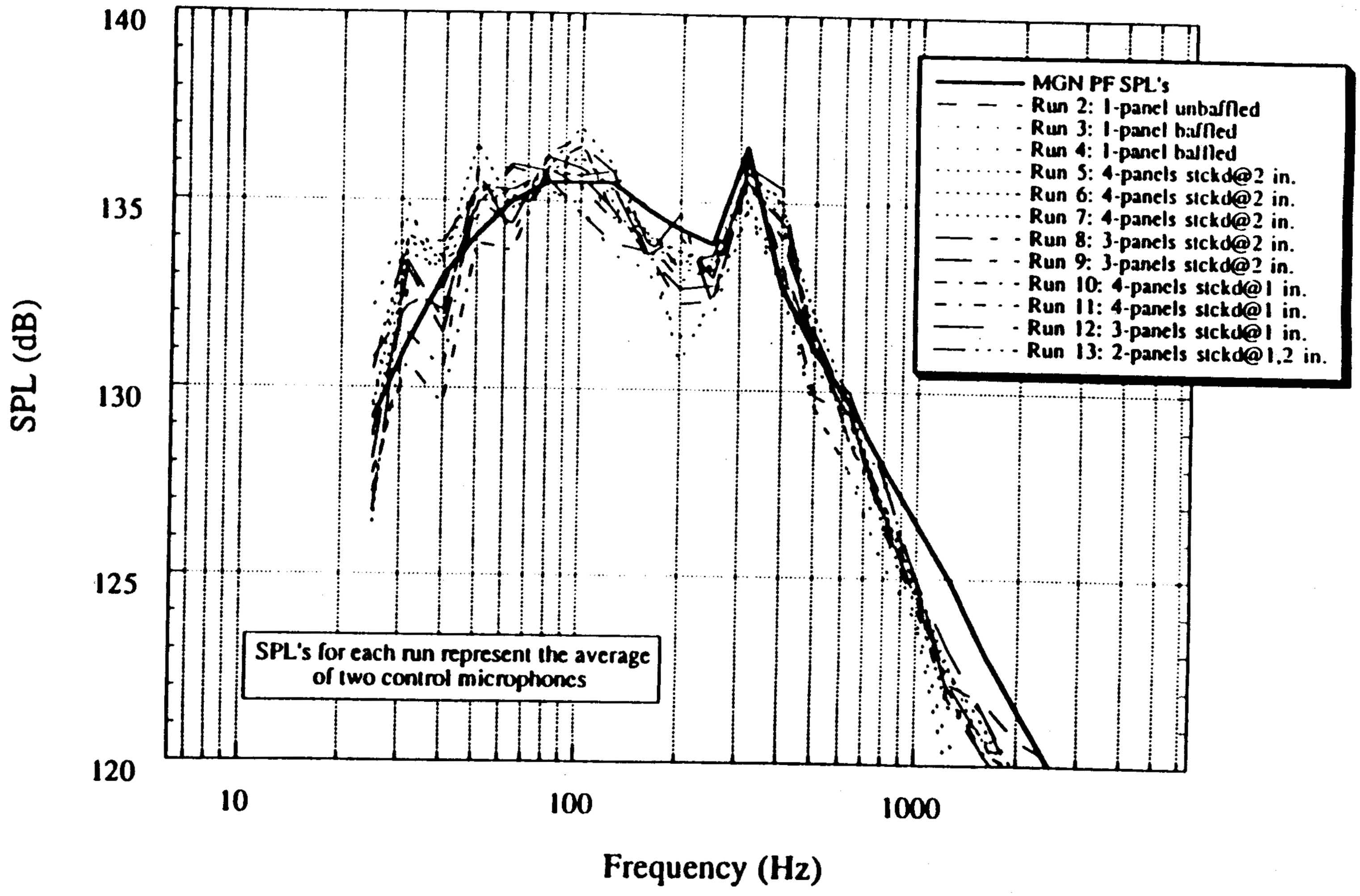


Figure 3.6 - Magellan Protoflight SPL's vs DMM Panel Acoustic Test SPL's

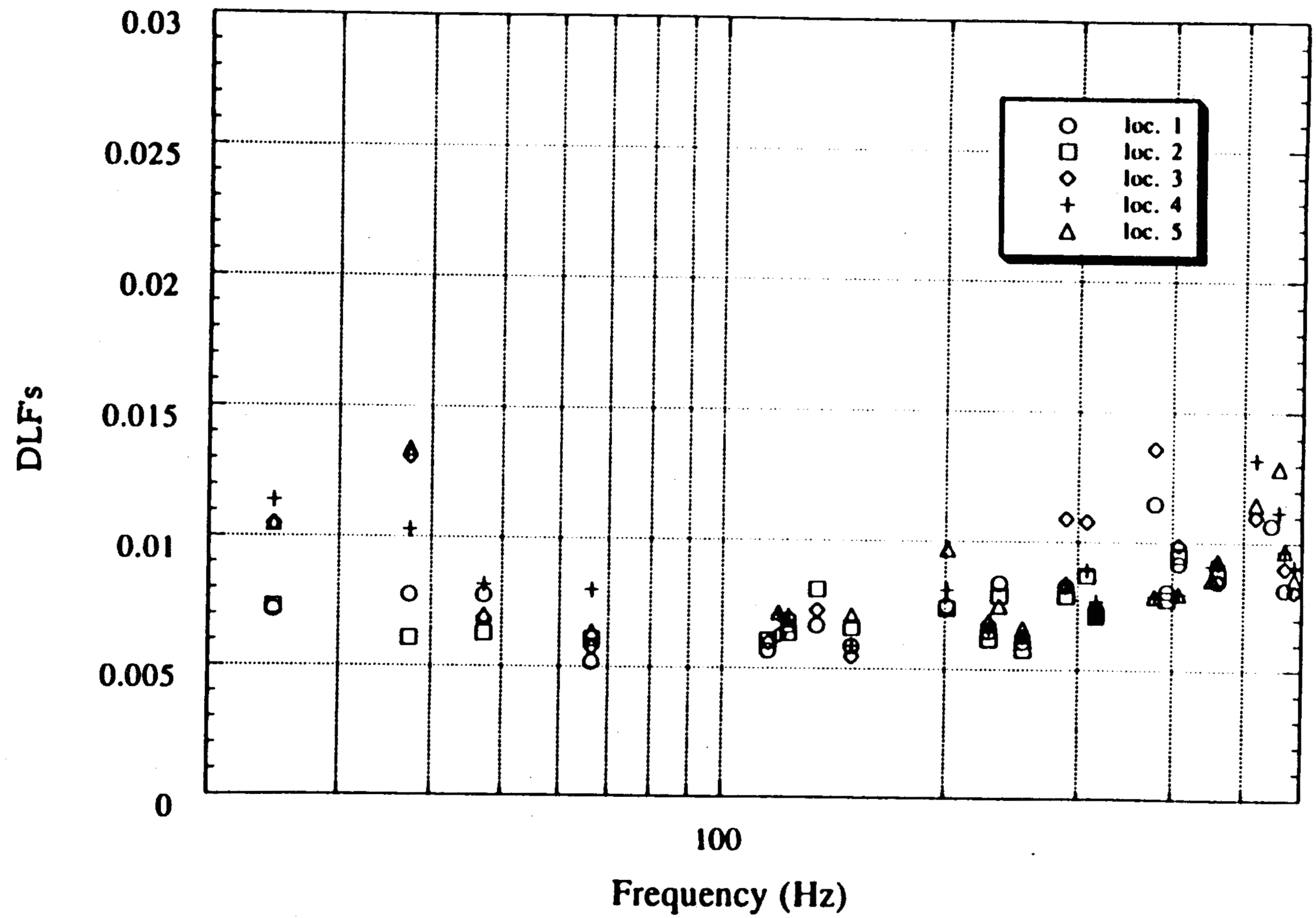


Figure 3.7 - Measured Damping Loss Factors for Single Unbaffled Panel

1/3-Octave Band Center Freq. (Hz)	1/3-Octave Band Edge Freq. (Hz)	Panel Modes (Hz)	No. of Modes	Modal Density
	22.4			
25.0		24.5	1	0.179
	28.0			
31.5		-	0	0.000
	35.5			
40.0		37.5	1	0.105
	45.0			
50.0		47	1	0.091
	56.0			
63.0		66.5	1	0.067
	71.0			
80.0		-	0	0.000
	90.0			
100.0		-	0	0.000
	112.0			
125.0		116,119,123,135	4	0.143
	140.0			
160.0		150	1	0.025
	180.0			
200.0		201	1	0.023
	224.0			
250.0		230,236,254,257	4	0.071
	280.0			
315.0		290,308.5,317	3	0.040
	355.0			
400.0		378,394,402,408	4	0.042
	450.0			
500.0		452,462,536,544,558	5	0.045
	560.0			

Table 3.2 - Measured 1/4-Panel Resonant Modes

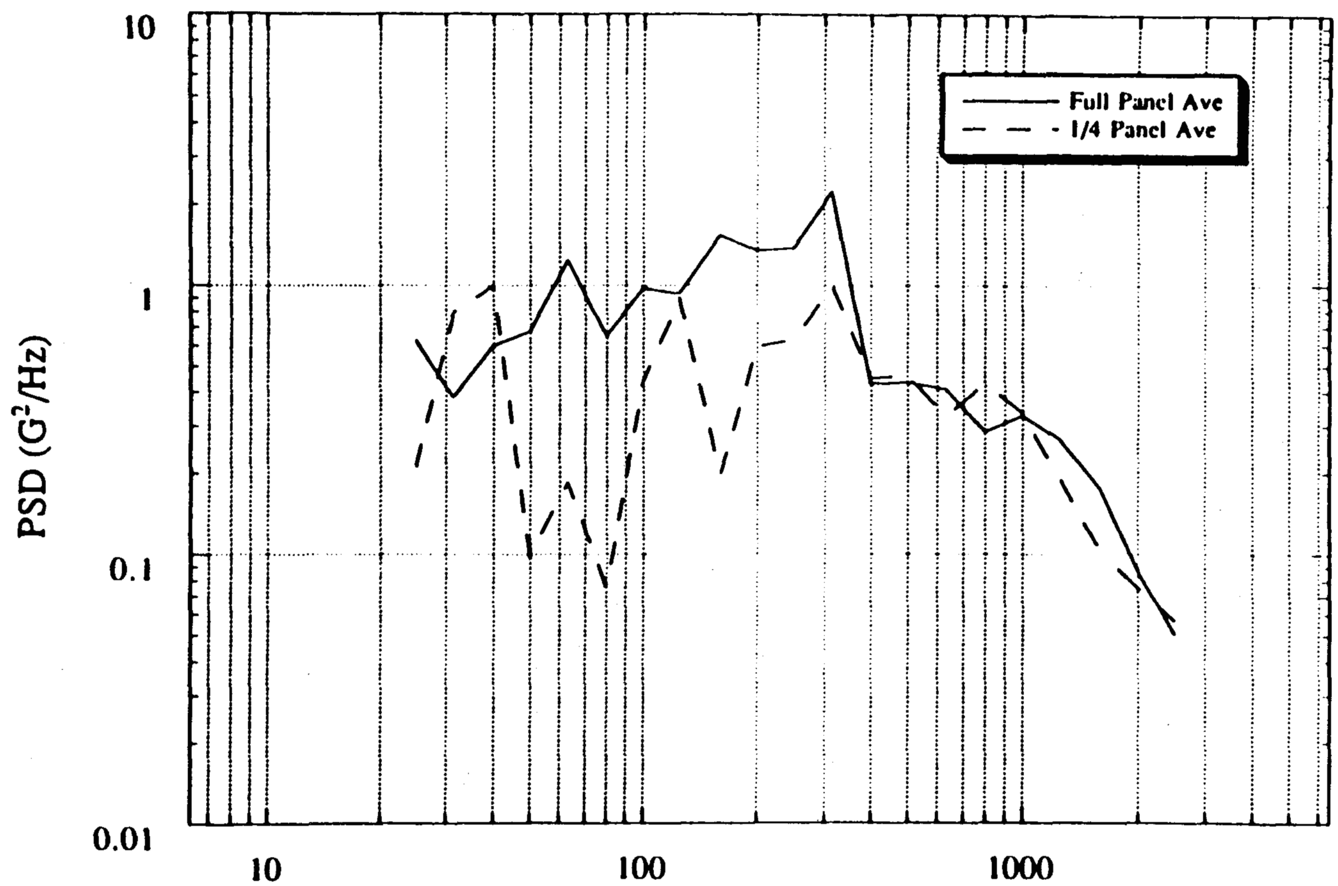


Figure 4.1 - Comparison of Full-Size DMM Panel to 1/4-Panel Acoustic Test Data

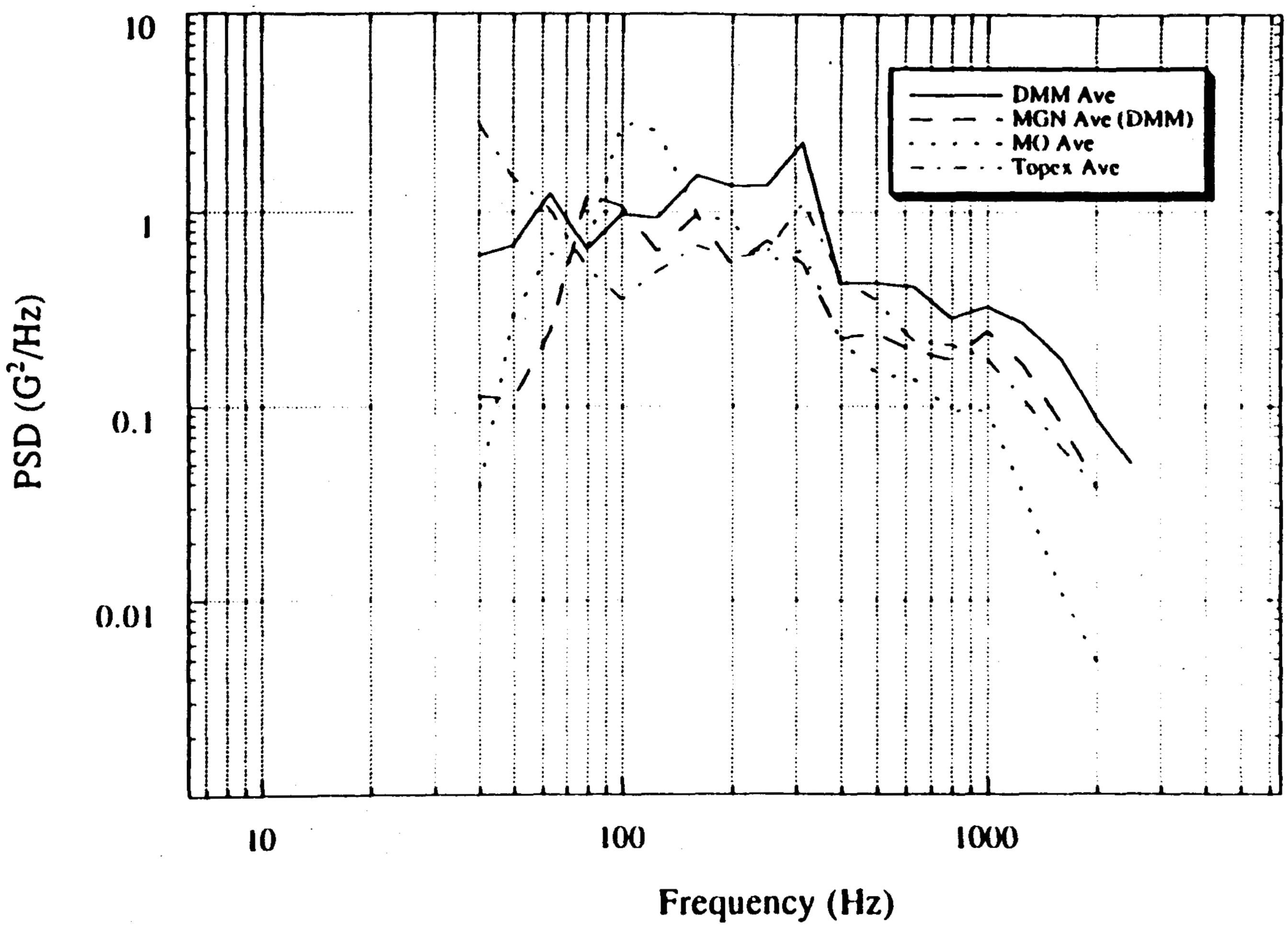


Figure 4.2 - Comparison of Magellan, MO, and TOPEX Panel Acoustic Test Data (Data is Normalized to Magellan PF SPL's)

Structural Parameters	Magellan DMModel	Mars Observer	TOPEX
Length (in.)	99.2	88.3	129.4
Width (in.)	98.2	72.0	75.8
Facesheet Thickness (in.)	0.015	0.01	0.012
Core Thickness (in.)	0.50	1.00	1.35
Facesheet Material	Aluminum	Kevlar	Aluminum
Core Material	Aluminum	Aluminum	Aluminum

Table 4.1 - Structural Parameters for Magellan,MO and TOPEX Solar Panels

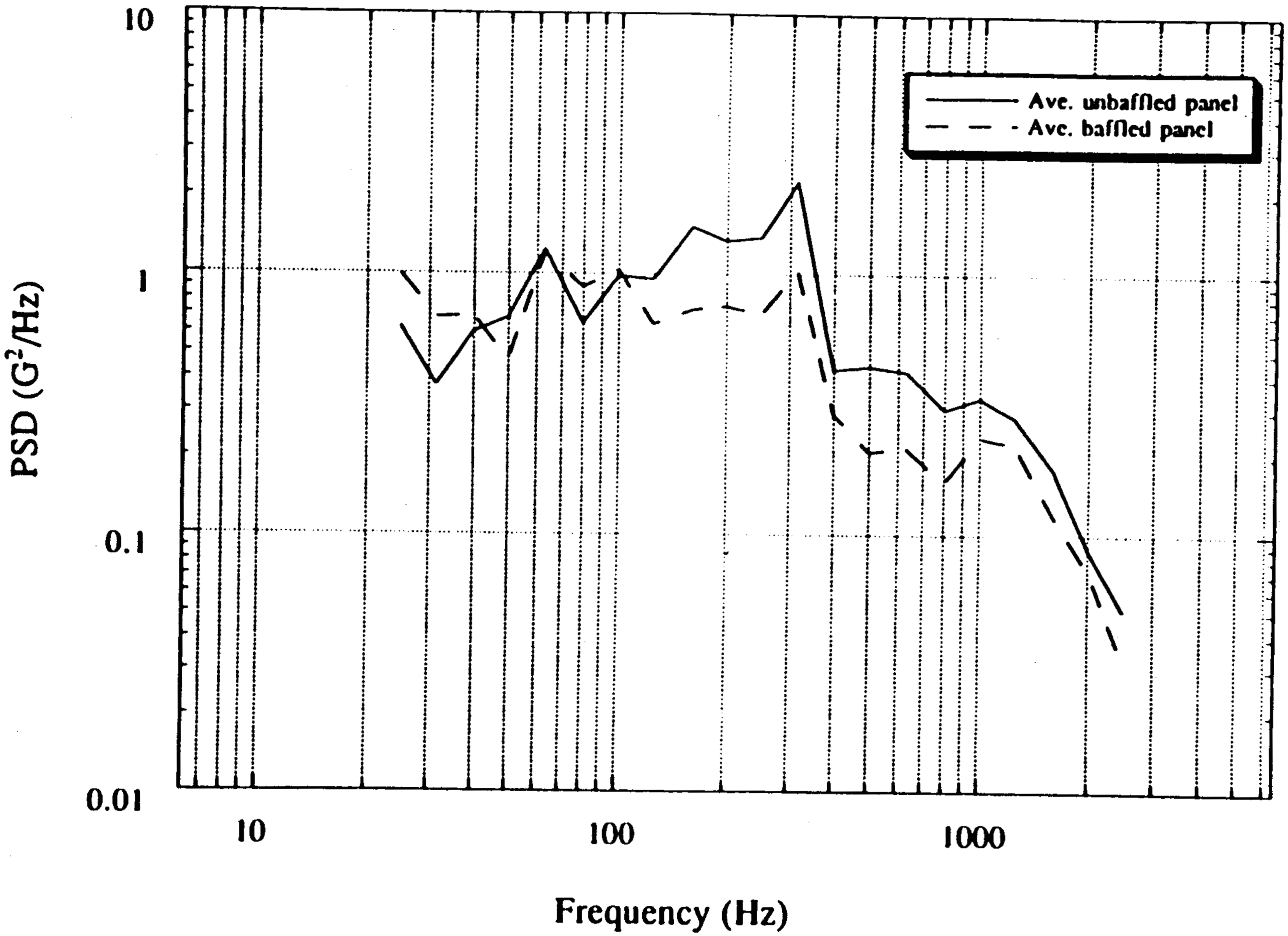


Figure 4.3 - Comparison of Full-size Panel Acoustic Test Data; Unbaffled vs Baffled Configuration

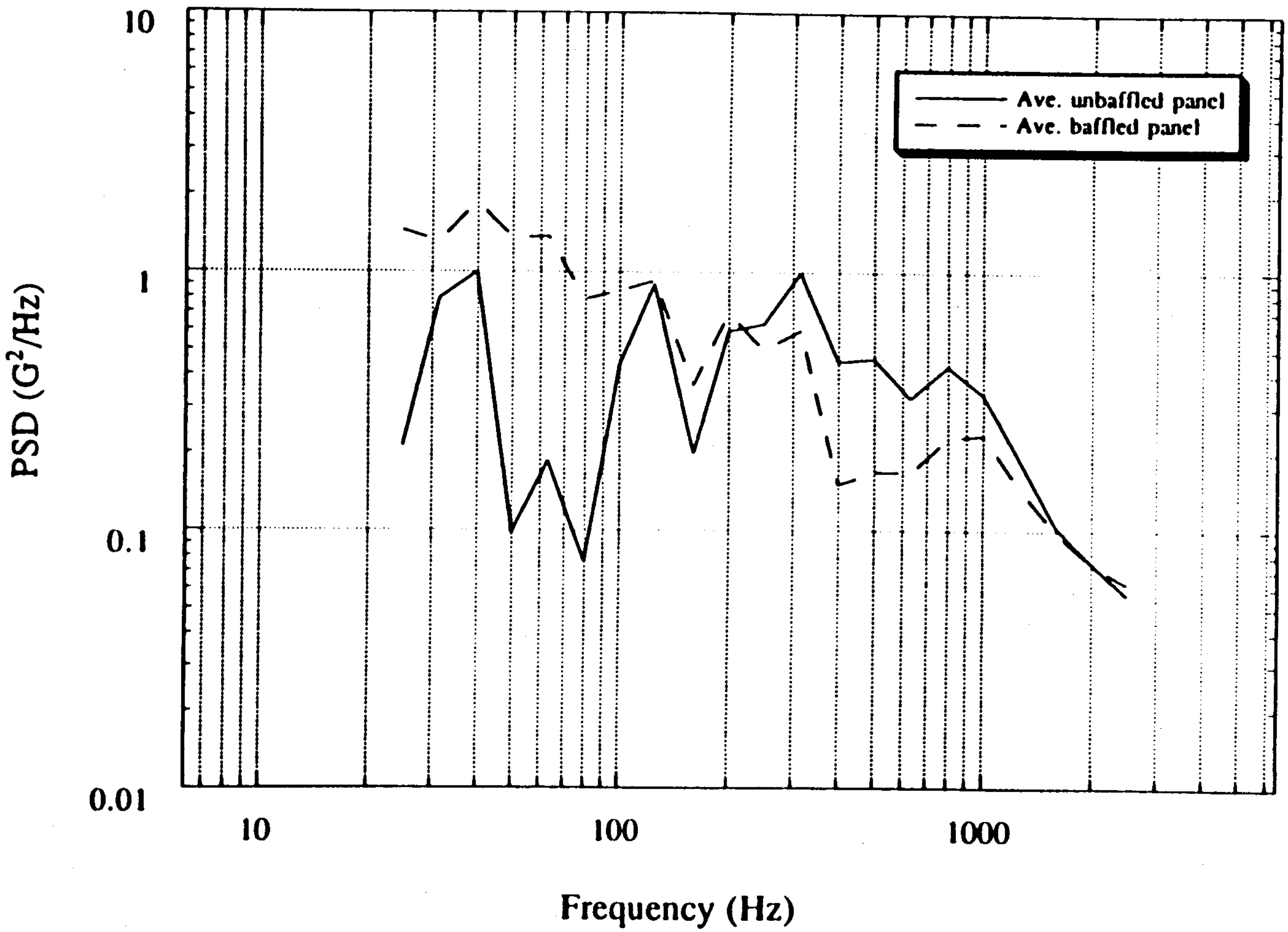


Figure 4.4 - Comparison of 1/4-Panel Acoustic Test Data; Unbaffled vs Baffled Configuration

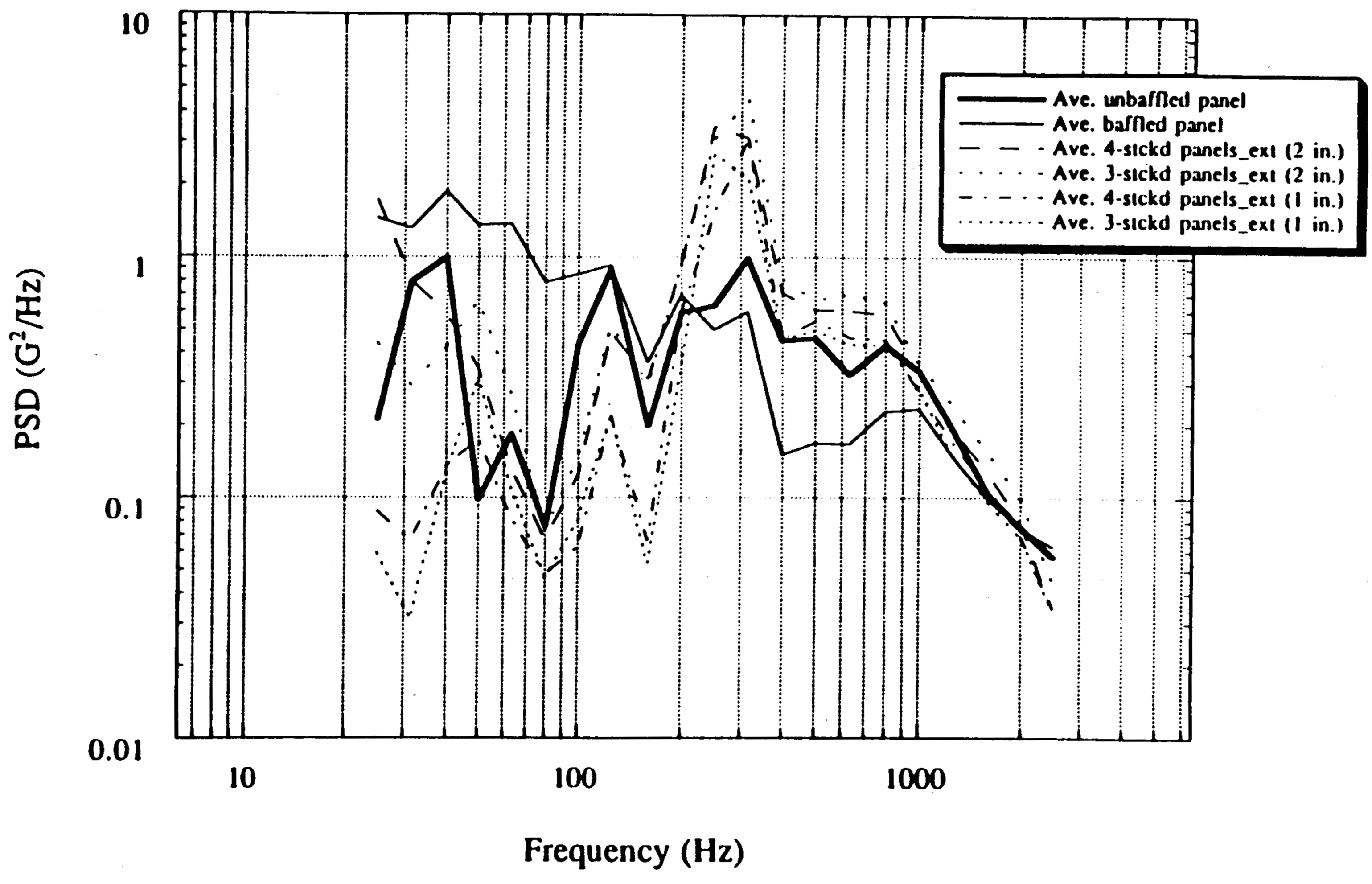


Figure 4.5 - Comparison of 1/4-Panel Acoustic Test Data; Single Unbaffled vs Exterior Panel in Various Stacks

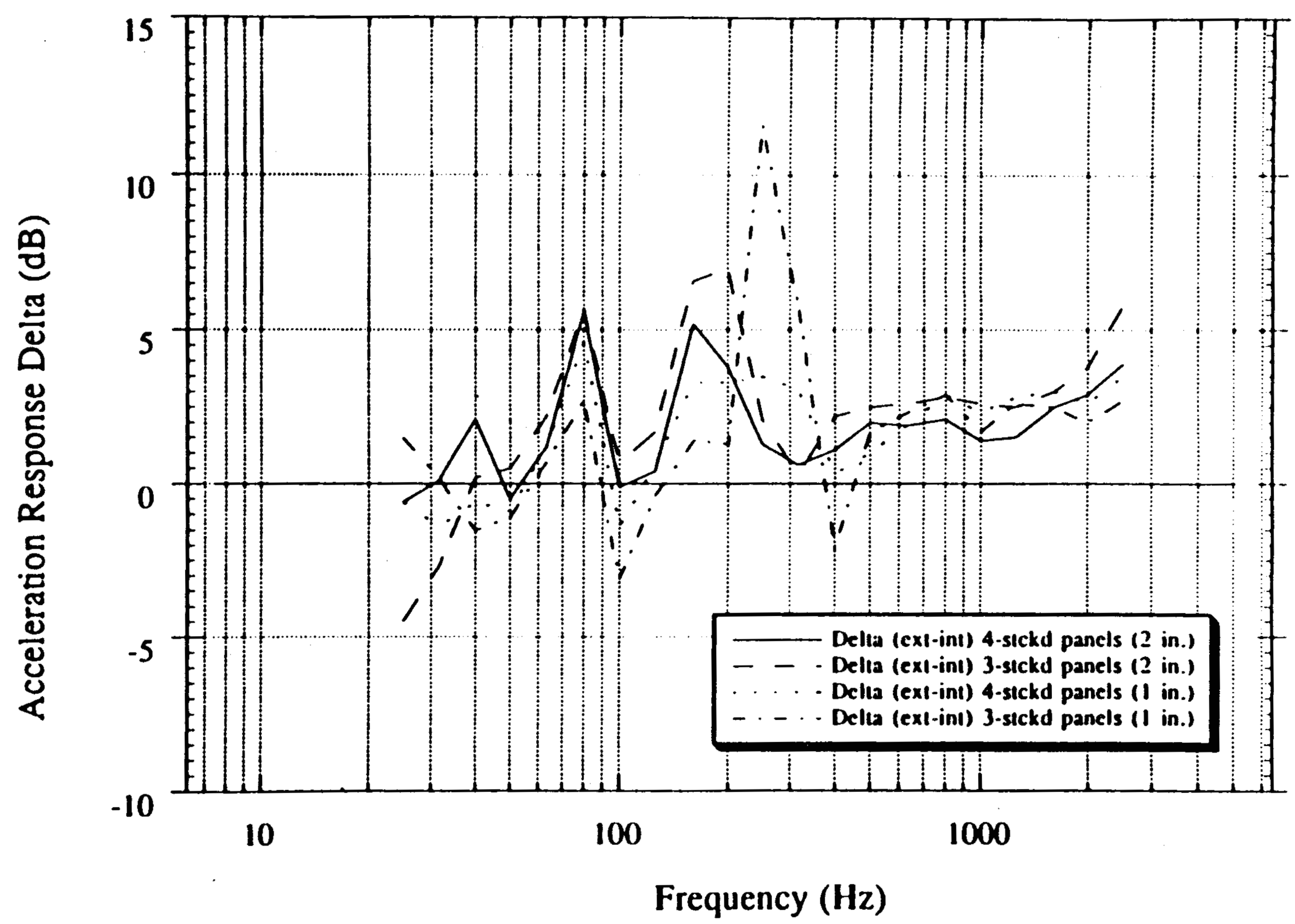


Figure 4.6 - Comparison of 1/4-Panel Acoustic Test Data; Ave. Response Difference between External and Internal Panels

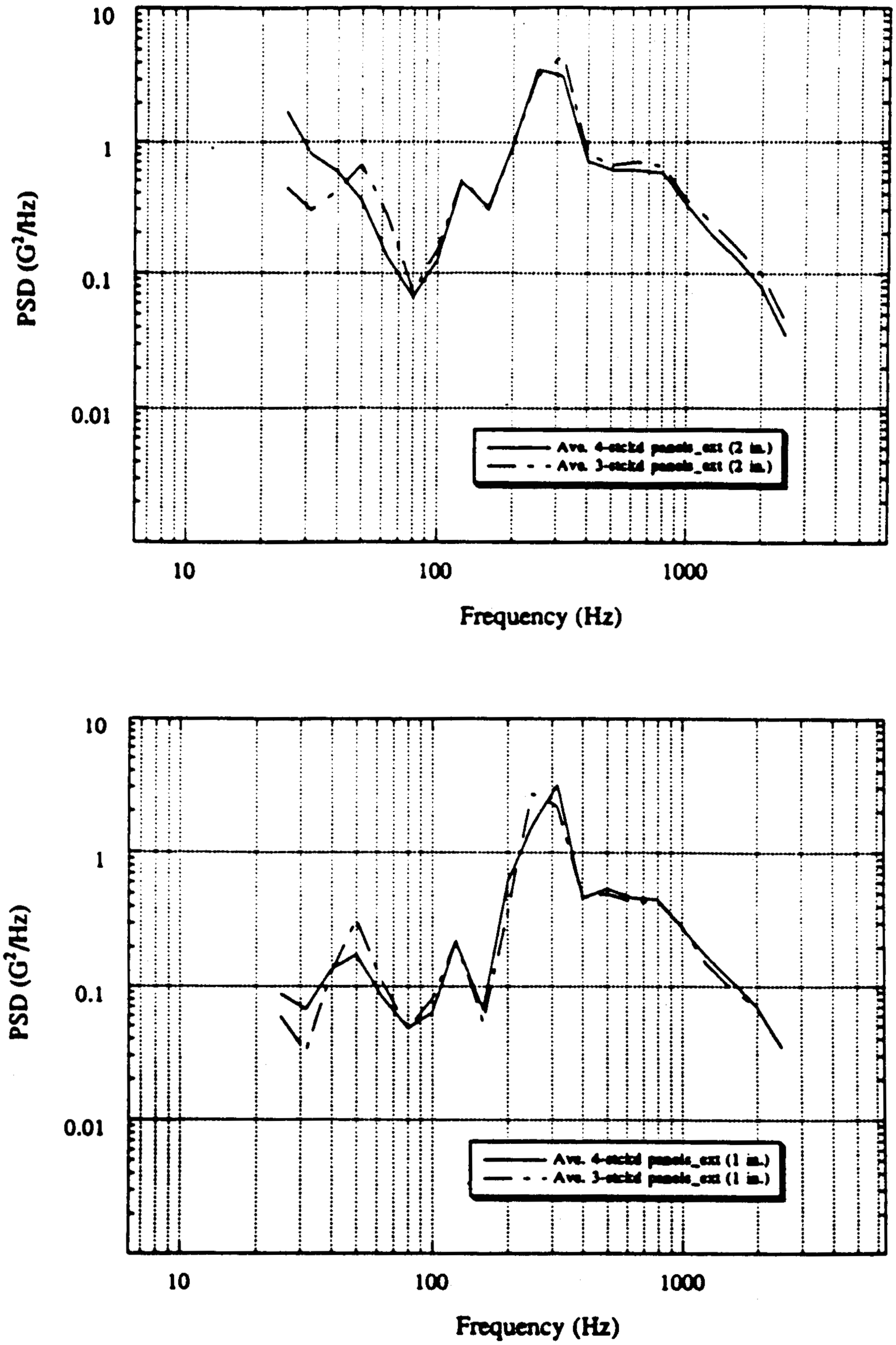
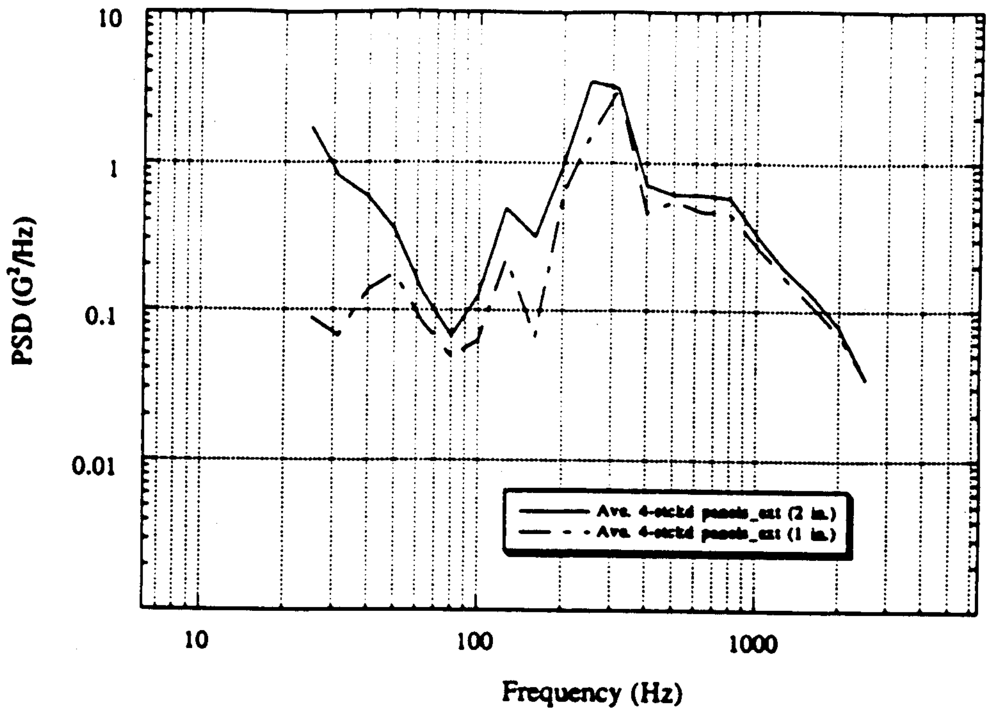


Figure 4.7 - Comparison of 1/4 Panel Acoustic Test Data; Response Difference between 3 vs 4 Panel Stack



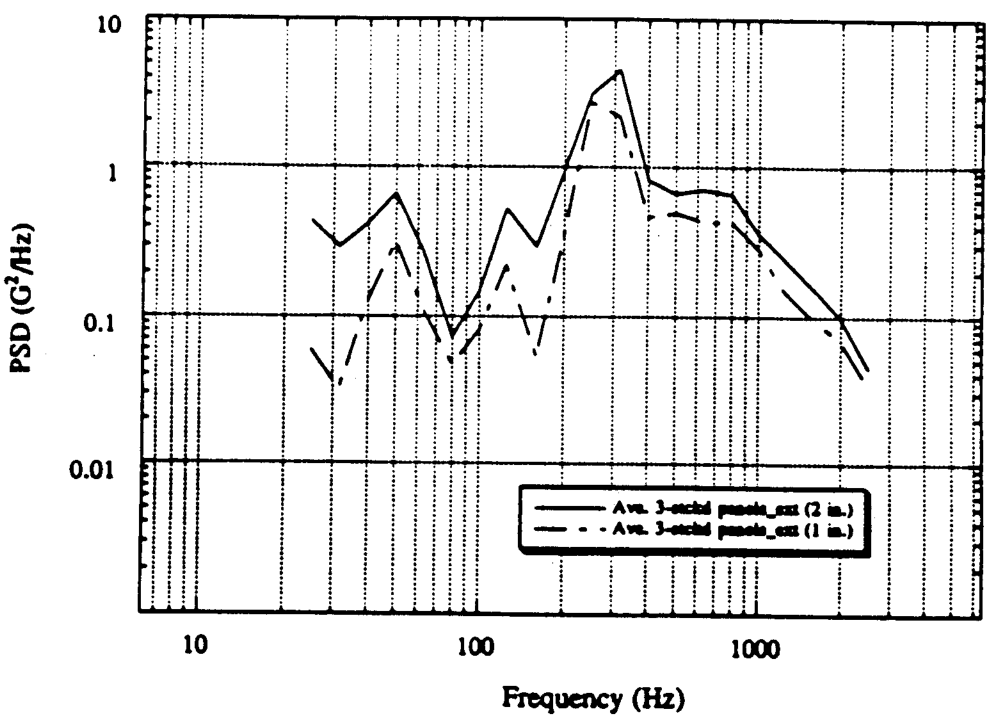
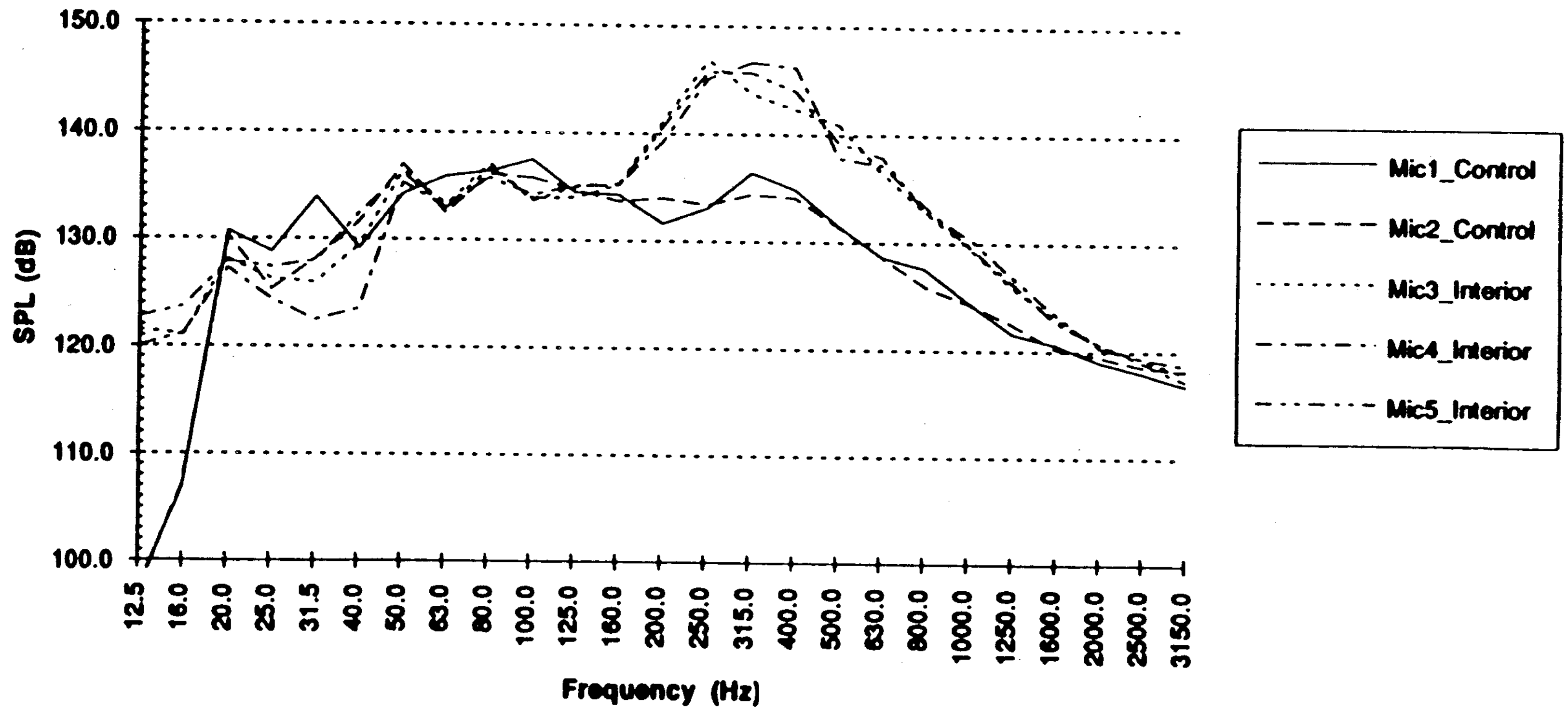
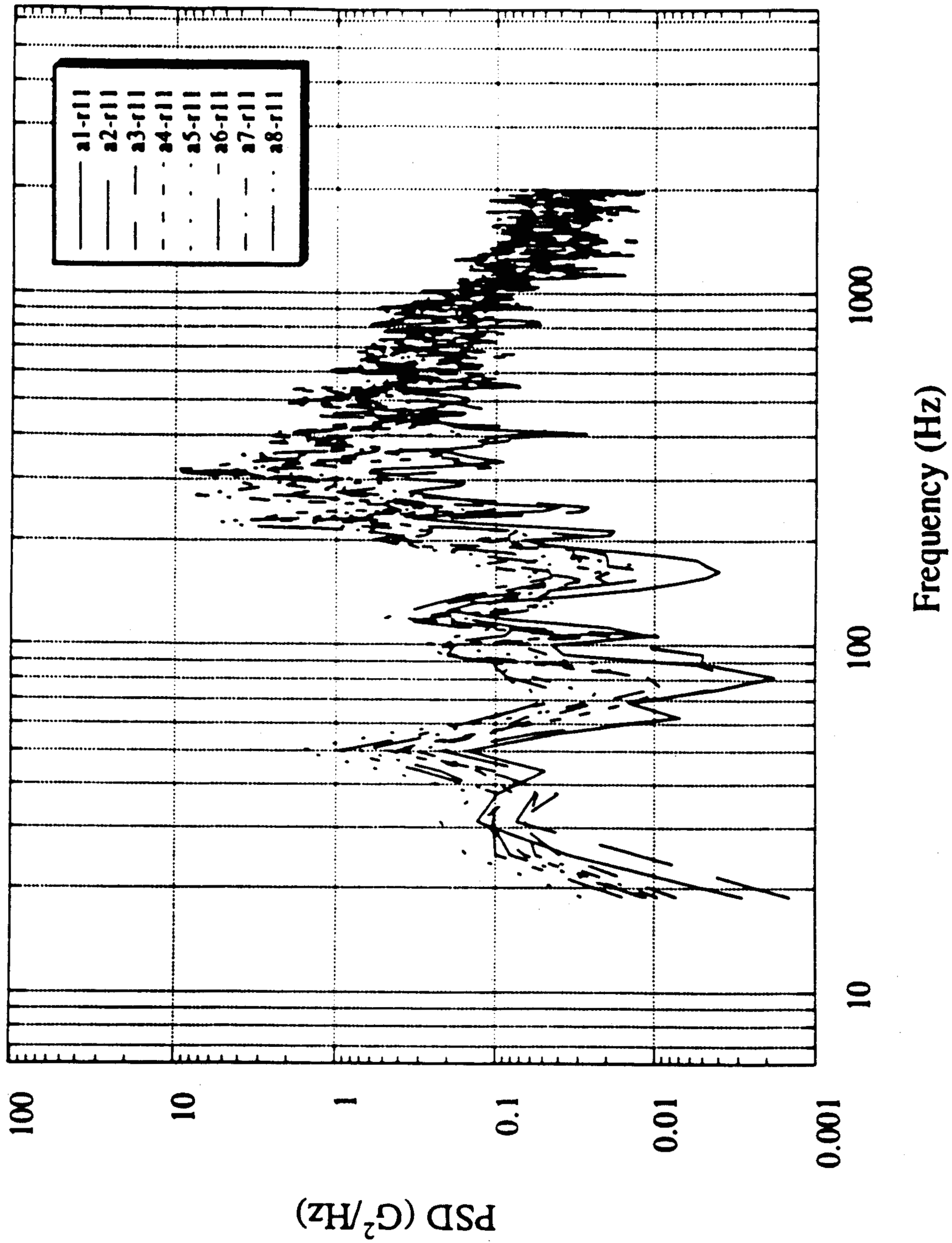


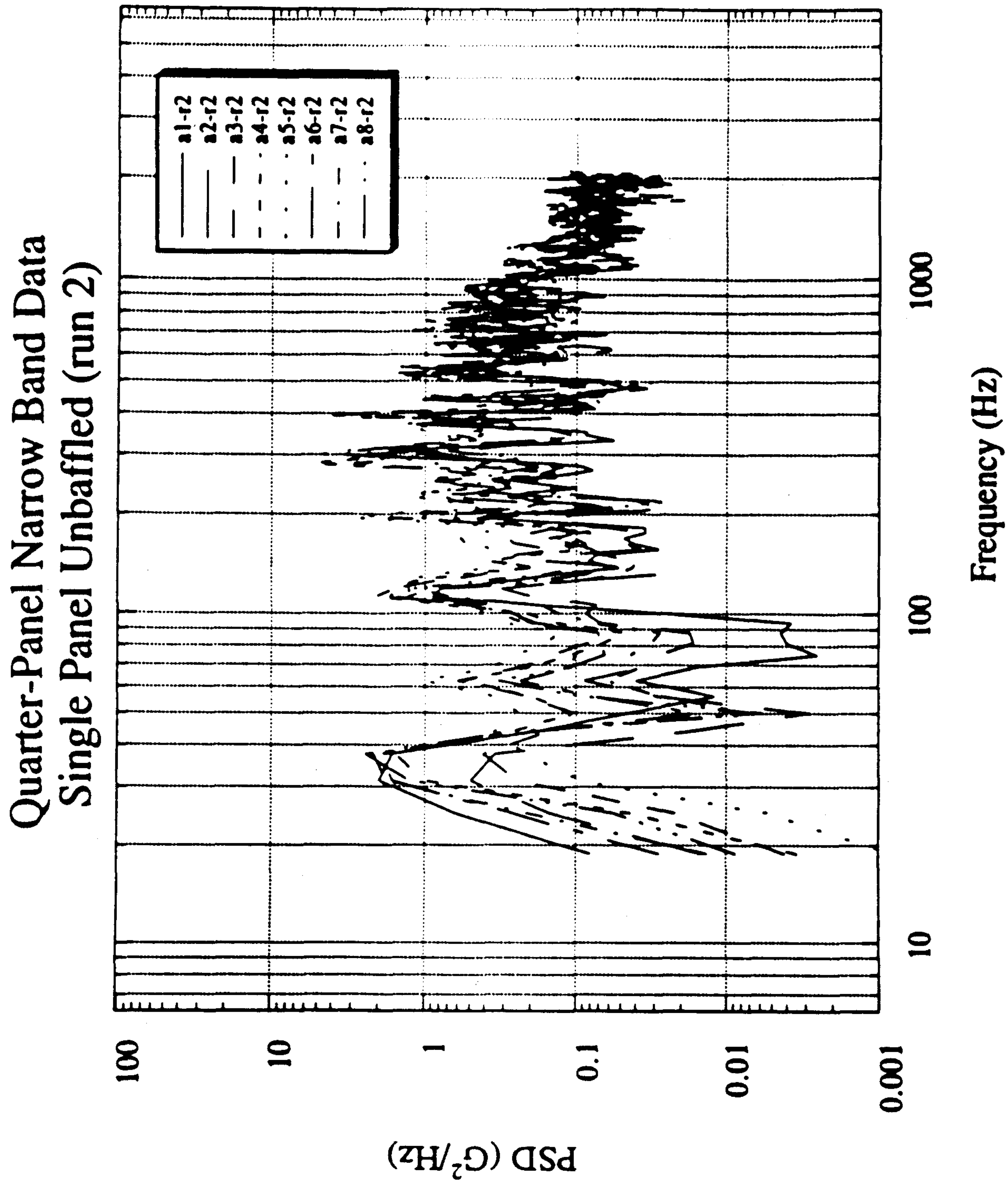
Figure 4.8 - Comparison of 1/4 Panel Acoustic Test Data; Response Difference of Stacked Panels with 1 vs 2 inch Gap

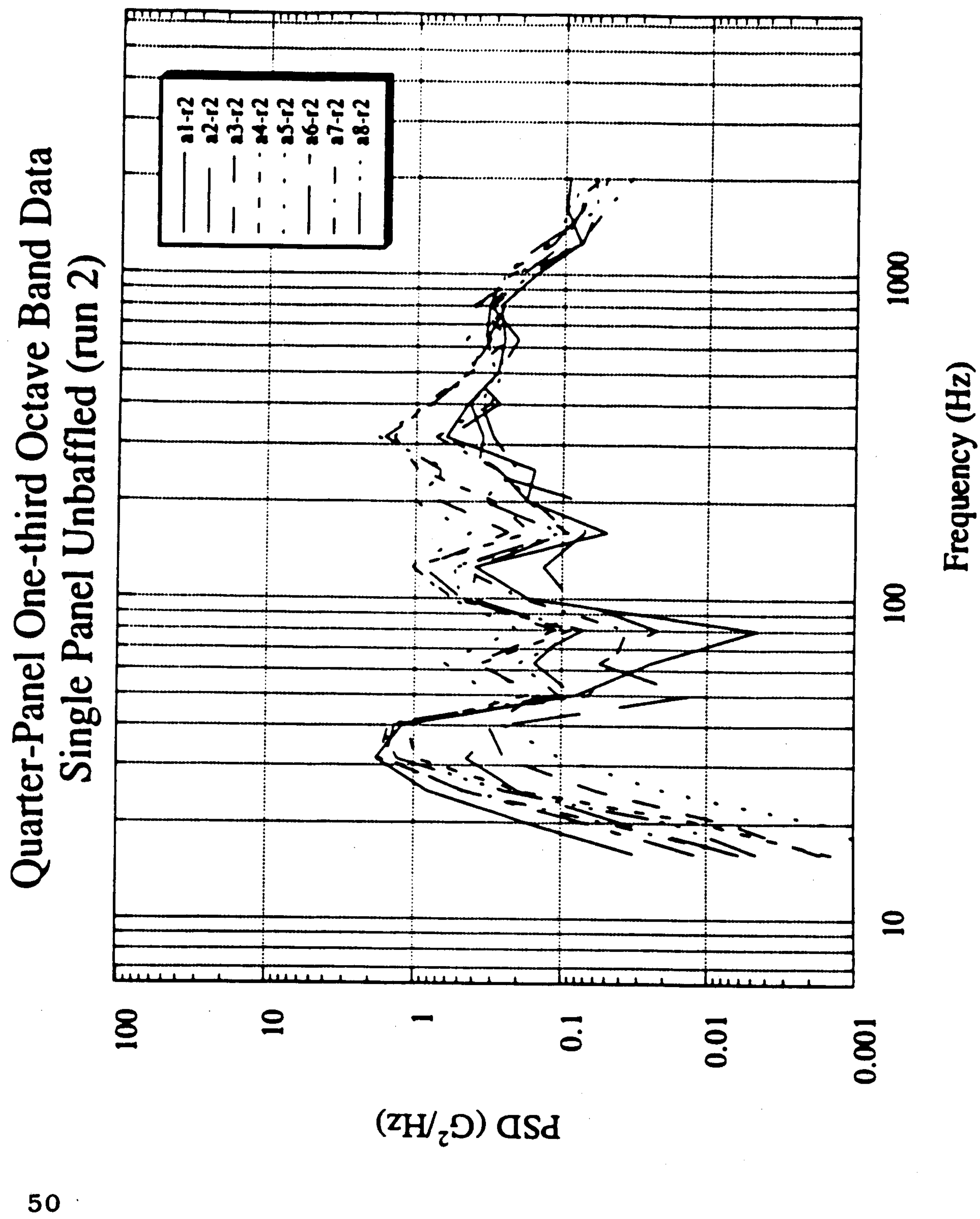
Acoustic SPL's - Four Stacked Panels @ 1 in (run 11)

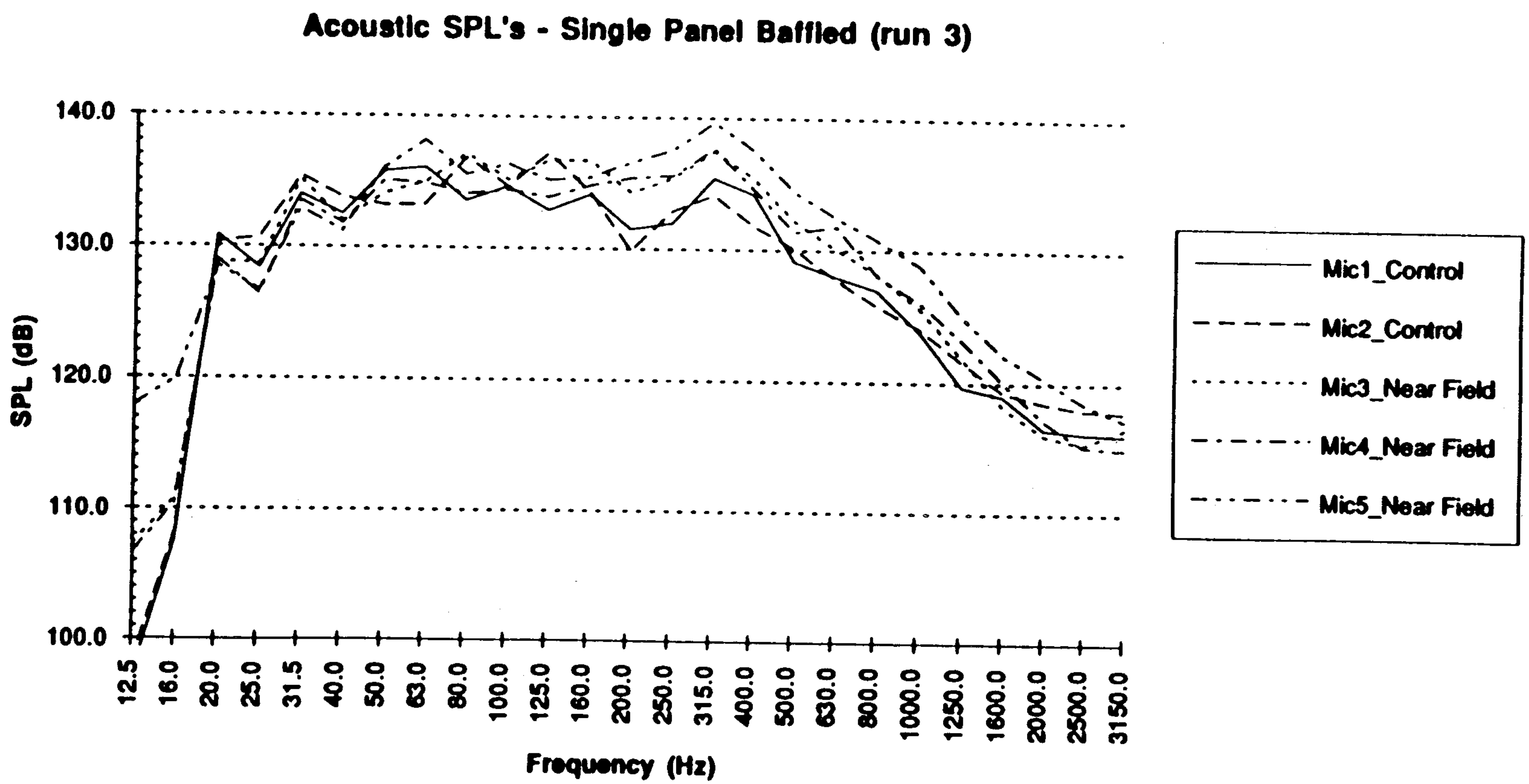


Quarter-Panel Narrow Band Data
Four Panels Stacked 1 in. Apart (run 11)

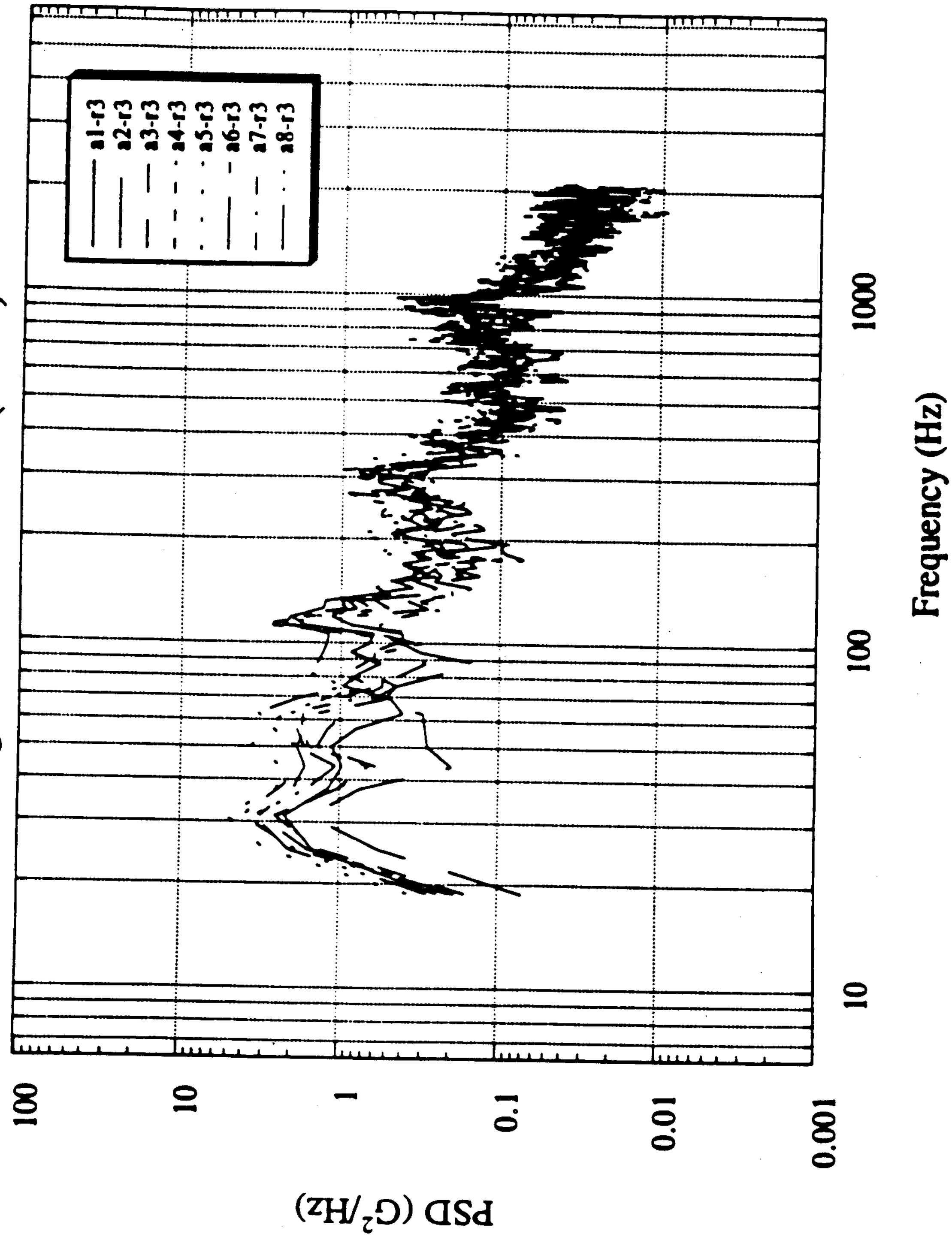


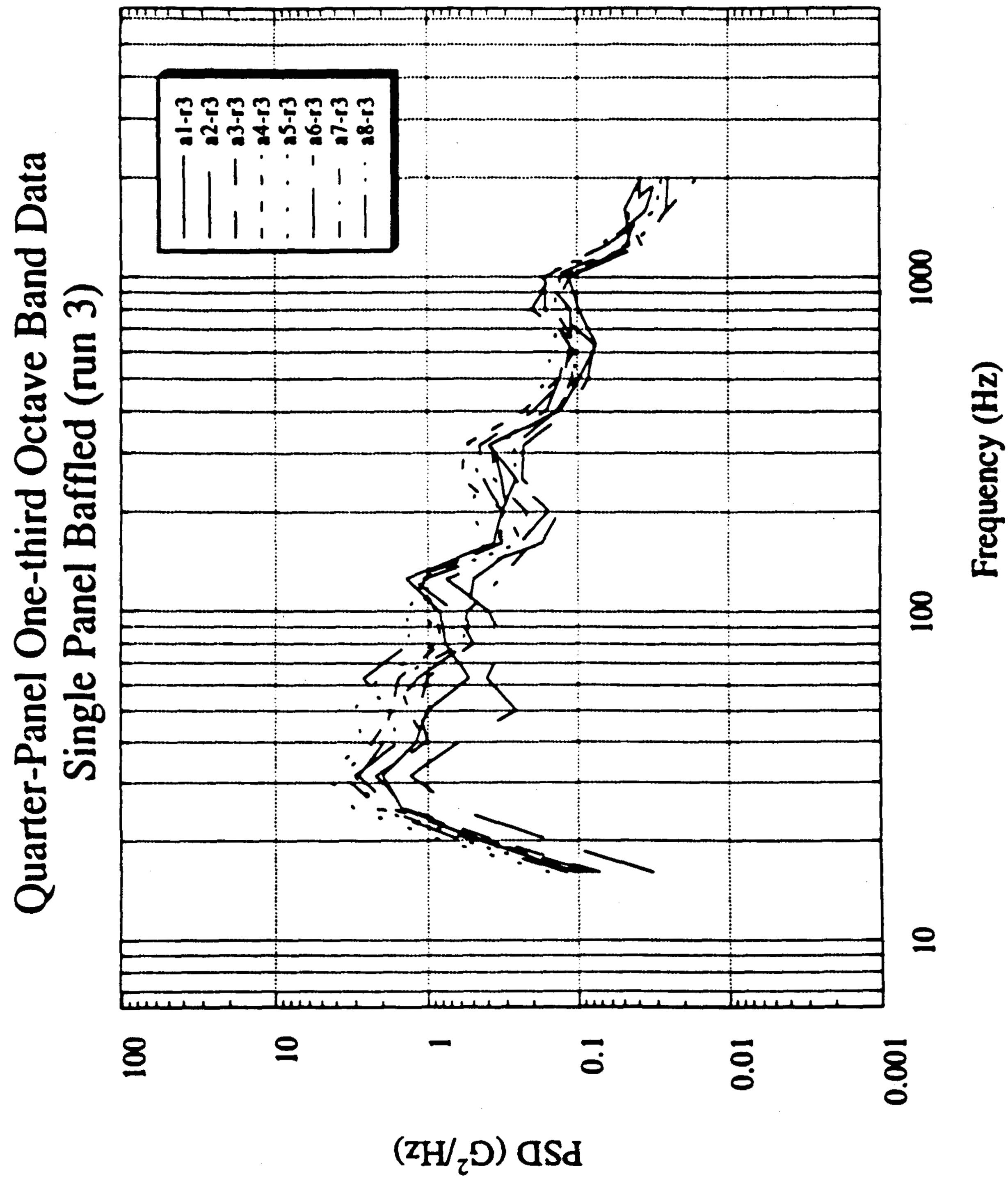

Quarter-Panel Narrow Band Data
Single Panel Unbaffled (run 2)
a1-r2
a2-r2
a3-r2
a4-r2
a5-r2
a6-r2
a7-r2
a8-r2
PSD (G^2/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)


Quarter-Panel One-third Octave Band Data
Single Panel Unbaffled (run 2)
a1-r2
a2-r2
a3-r2
a4-r2
a5-r2
a6-r2
a7-r2
a8-r2
100
10
1
0.1
0.01
0.001
PSD (G²/Hz)
10
100
1000
Frequency (Hz)

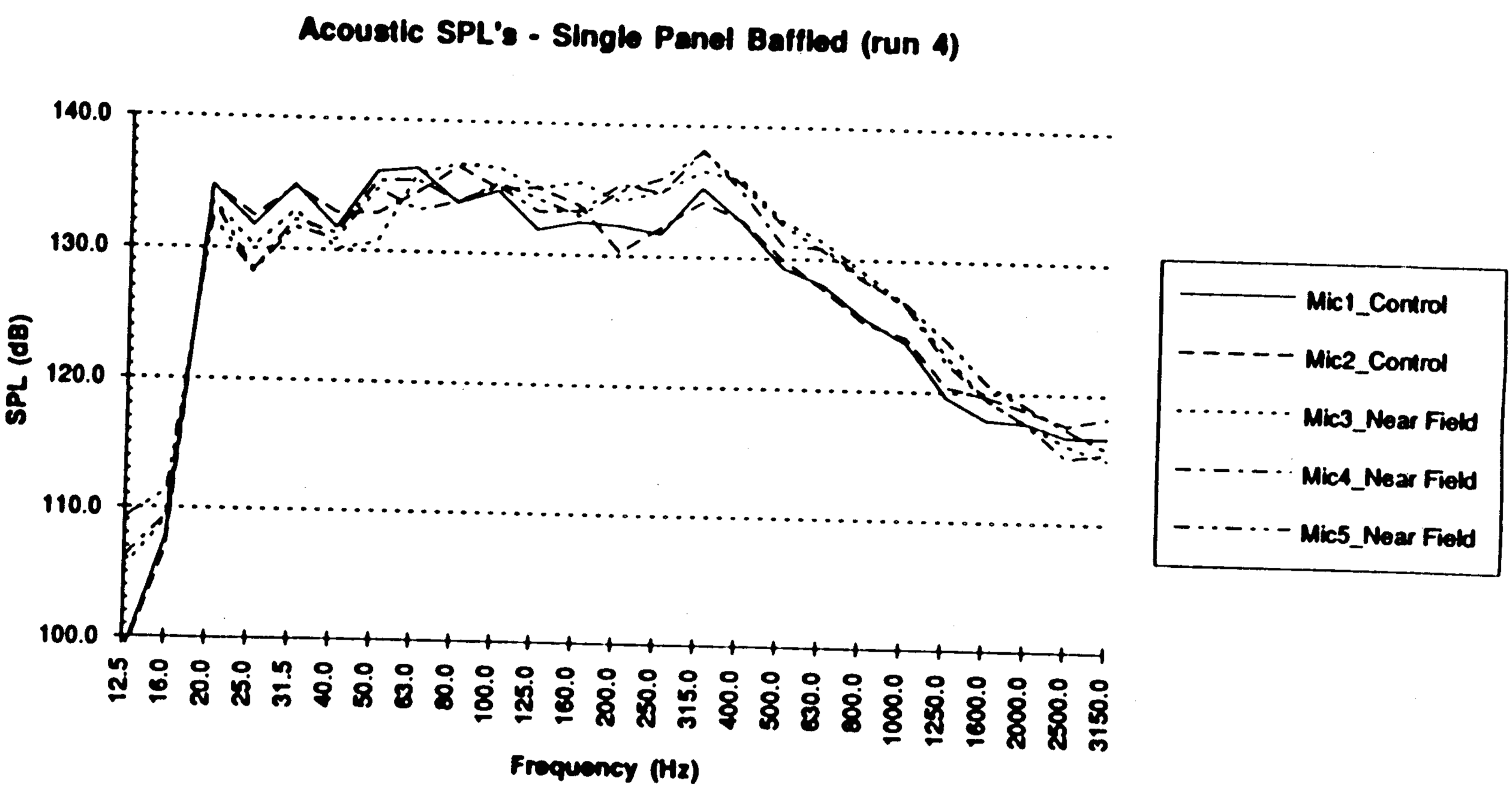

Acoustic SPL's - Single Panel Baffled (run 3)
SPL (dB)
140.0
130.0
120.0
110.0
100.0
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0
Frequency (Hz)
Mic1_Control
Mic2_Control
Mic3_Near Field
Mic4_Near Field
Mic5_Near Field

Quarter-Panel Narrow Band Data
Single Panel Baffled (run 3)

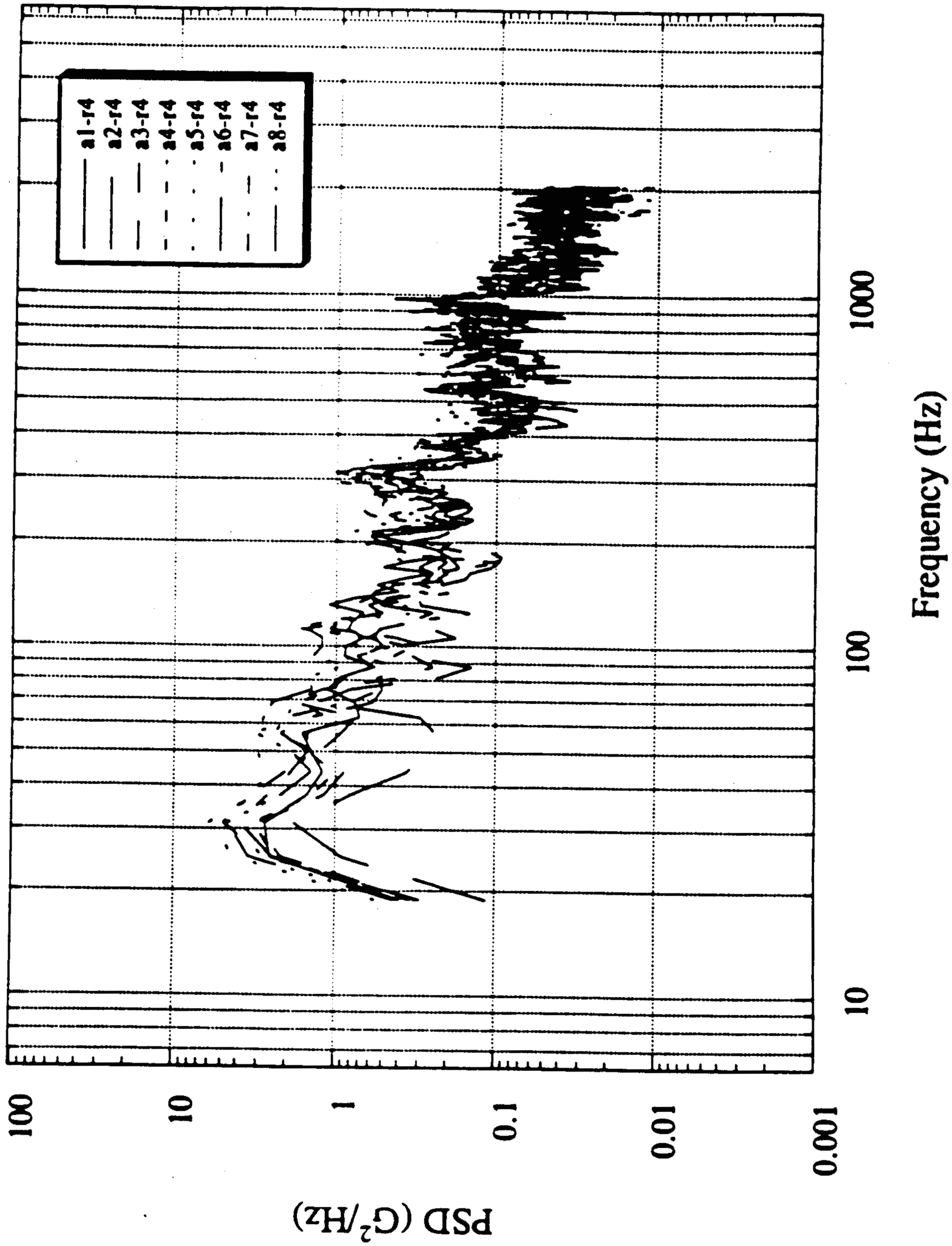




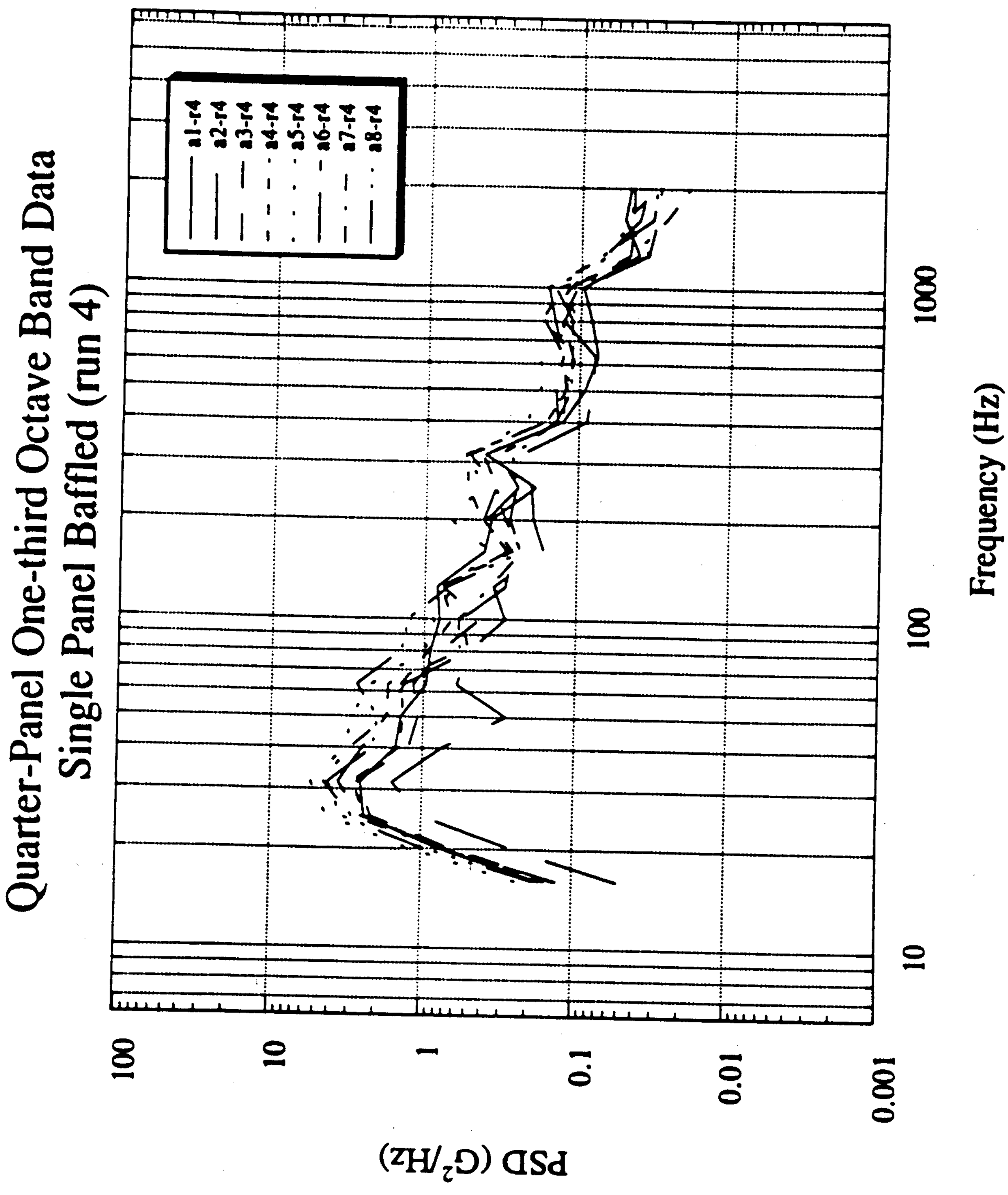
Quarter-Panel One-third Octave Band Data
Single Panel Baffled (run 3)
a1-r3
a2-r3
a3-r3
a4-r3
a5-r3
a6-r3
a7-r3
a8-r3
100
10
1
0.1
0.01
0.001
PSD (G²/Hz)
10
100
1000
Frequency (Hz)



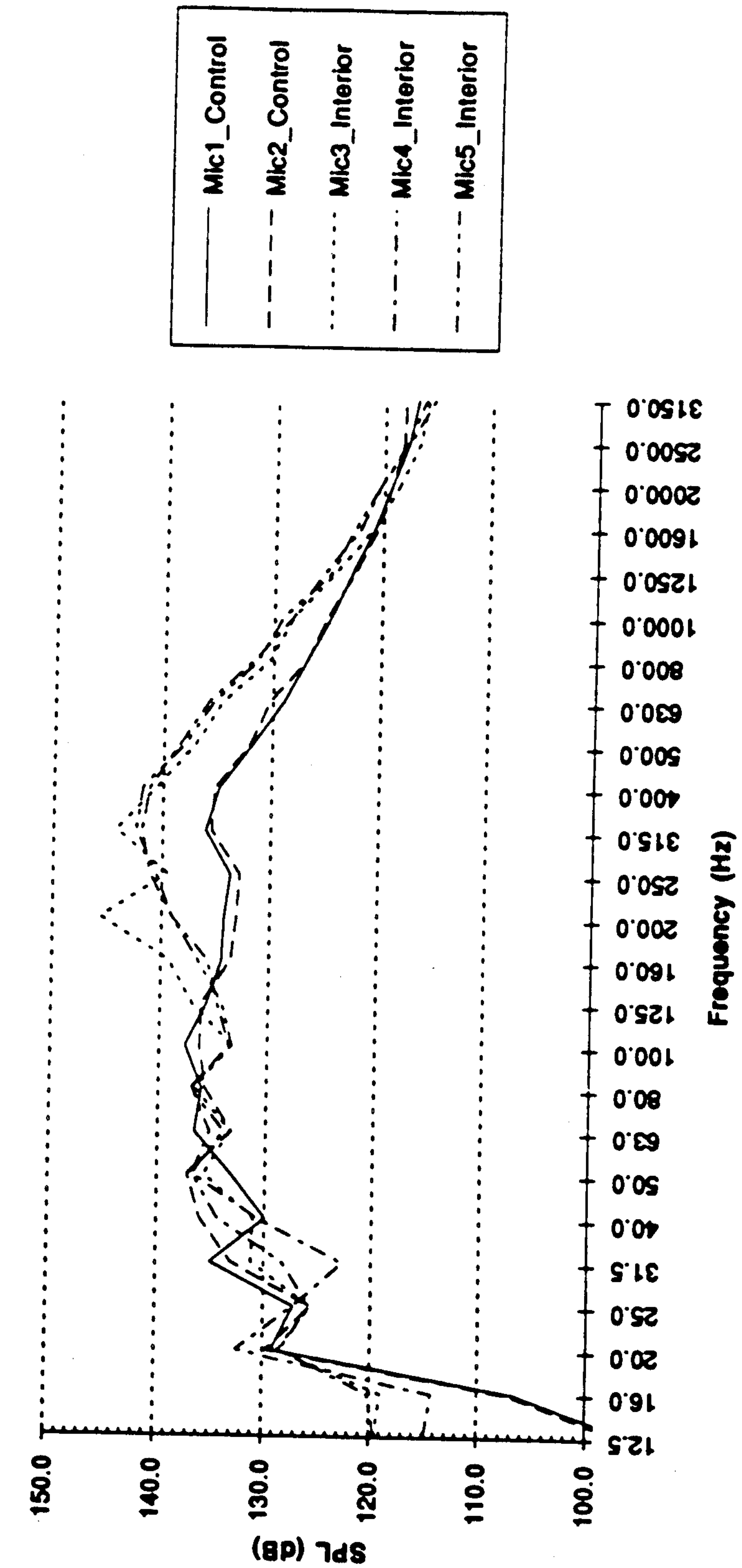
Acoustic SPL's - Single Panel Baffled (run 4)
SPL (dB)
140.0
130.0
120.0
110.0
100.0
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0
Frequency (Hz)
Mic1_Control
Mic2_Control
Mic3_Near Field
Mic4_Near Field
Mic5_Near Field

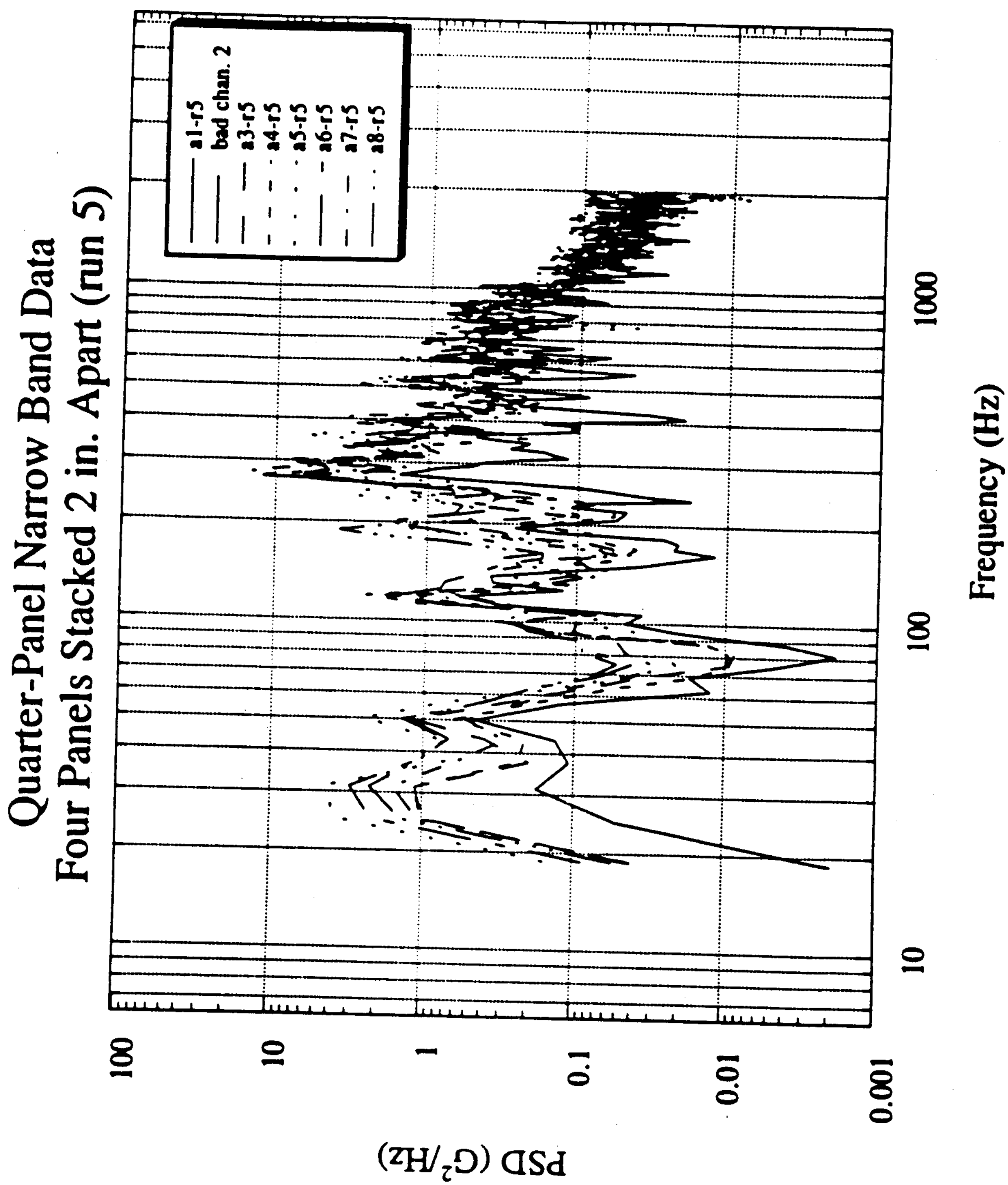


Quarter-Panel Narrow Band Data
Single Panel Baffled (run 4)


Quarter-Panel One-third Octave Band Data
Single Panel Baffled (run 4)
a1-r4
a2-r4
a3-r4
a4-r4
a5-r4
a6-r4
a7-r4
a8-r4
Frequency (Hz)
10
100
1000
PSD (G^2/Hz)
100
10
1
0.1
0.01
0.001

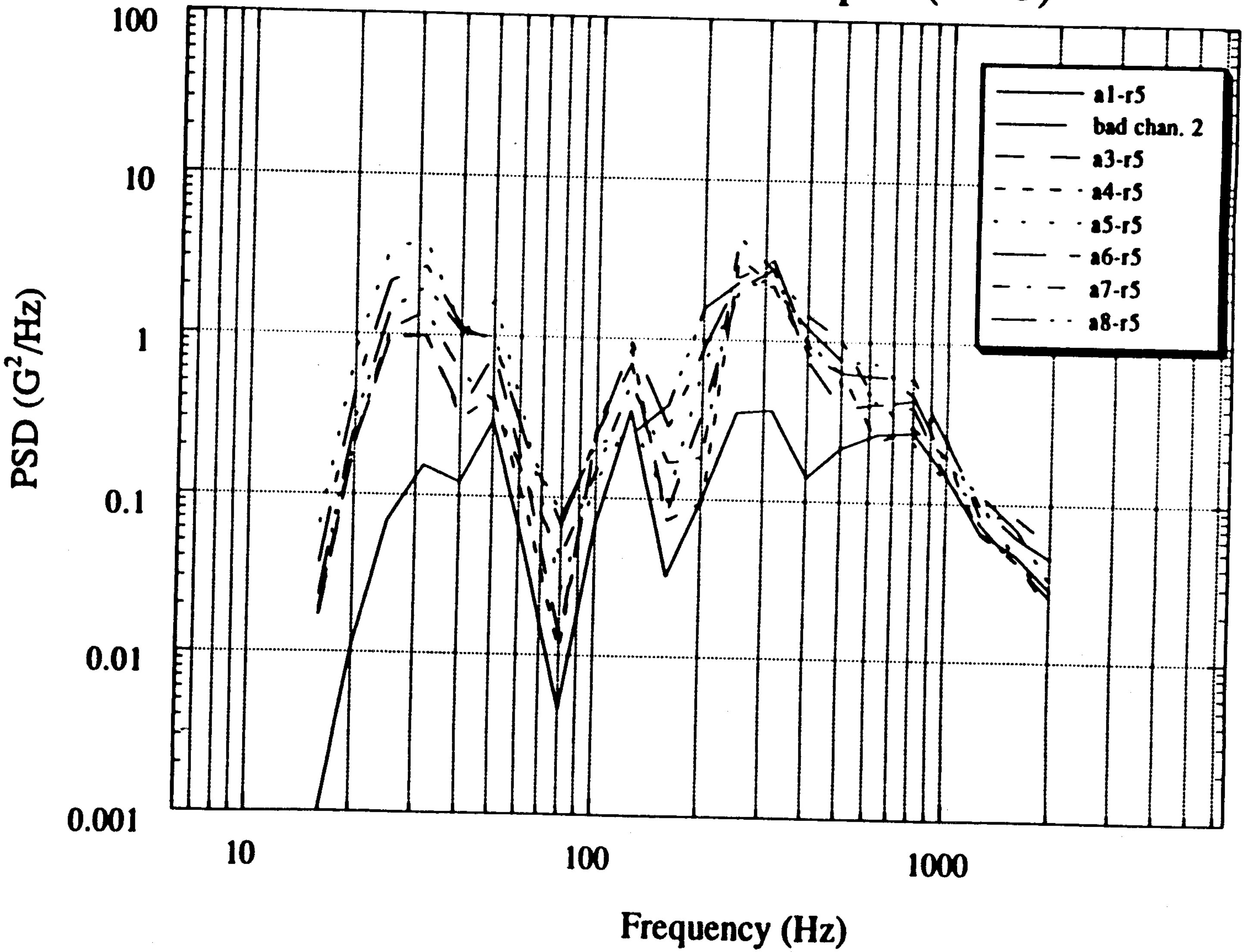
Acoustic SPL's - Four Stacked Panels @ 2 in (run 5)

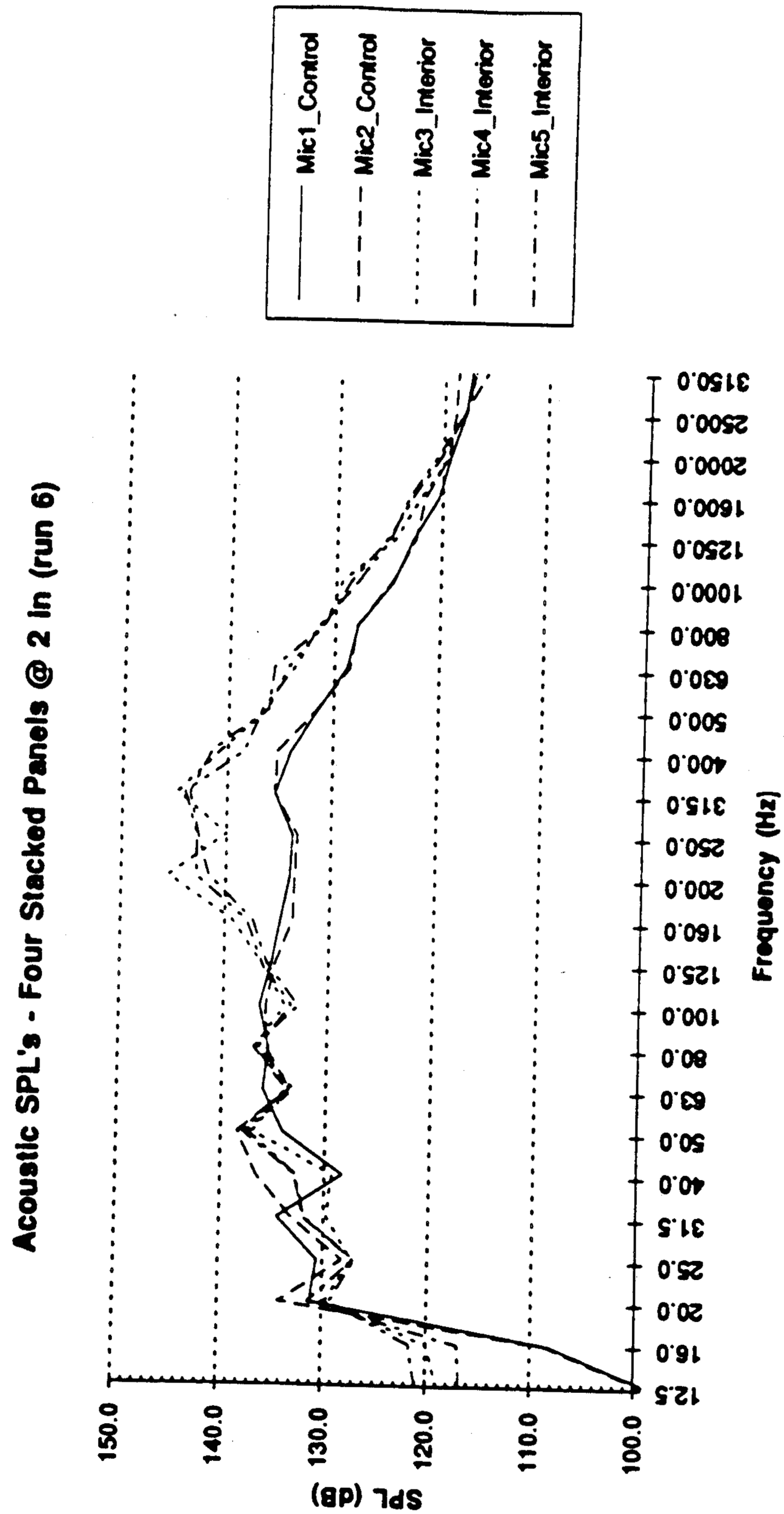


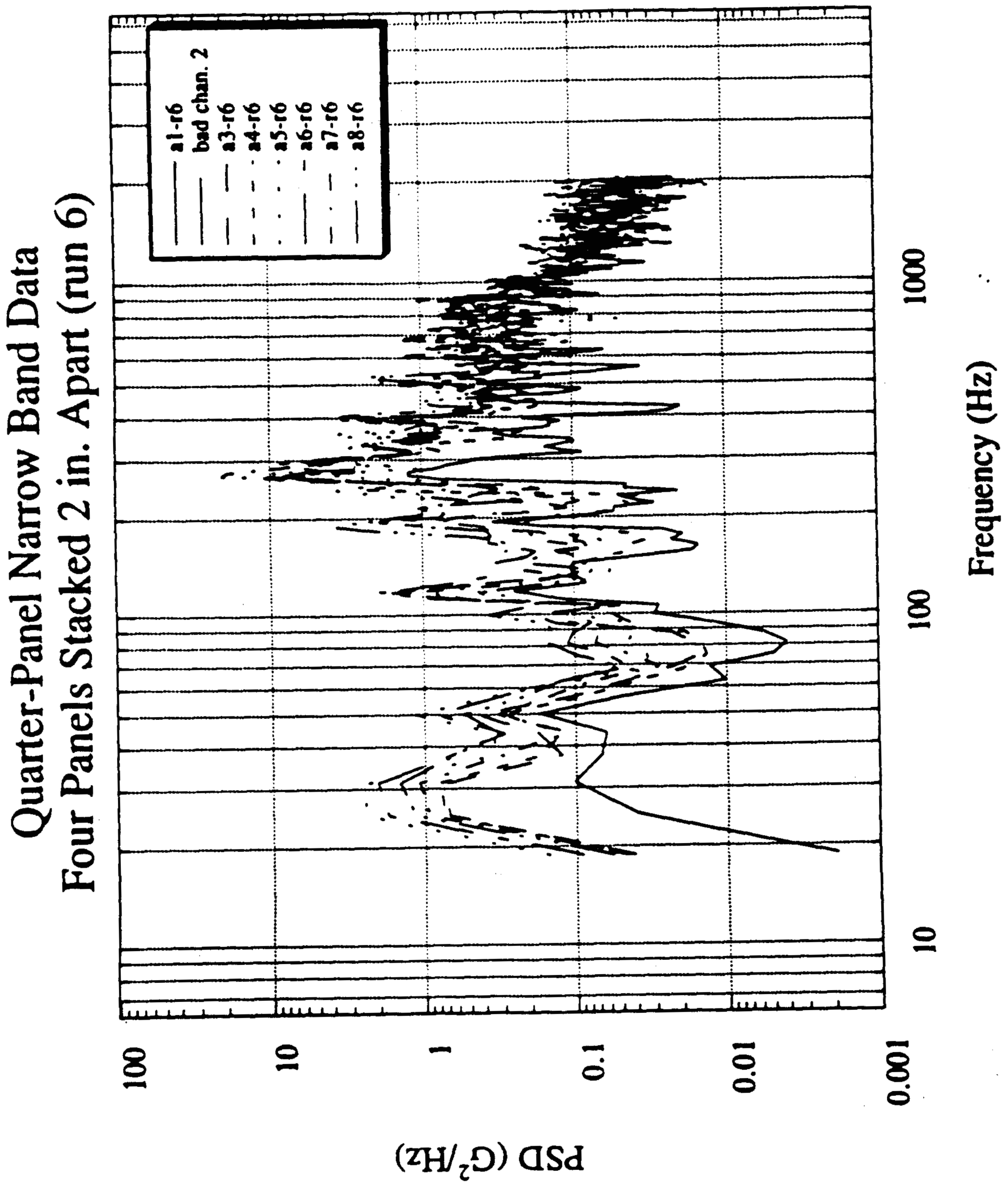


Quarter-Panel Narrow Band Data
Four Panels Stacked 2 in. Apart (run 5)
a1-r5
bad chan. 2
a3-r5
a4-r5
a5-r5
a6-r5
a7-r5
a8-r5
PSD (G²/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)

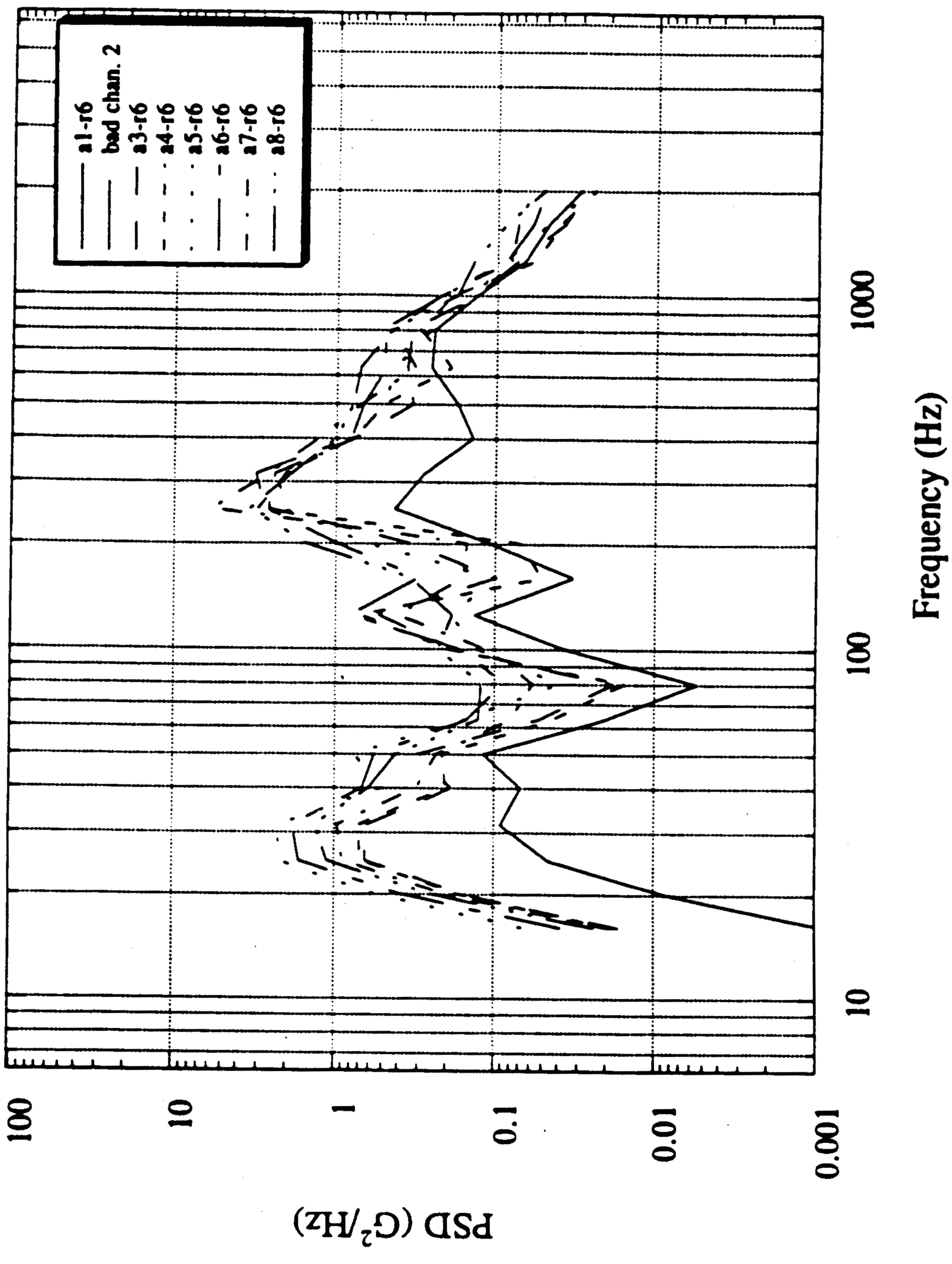
Quarter-Panel One-third Octave Band Data
Four Panels Stacked 2 in. Apart (run 5)

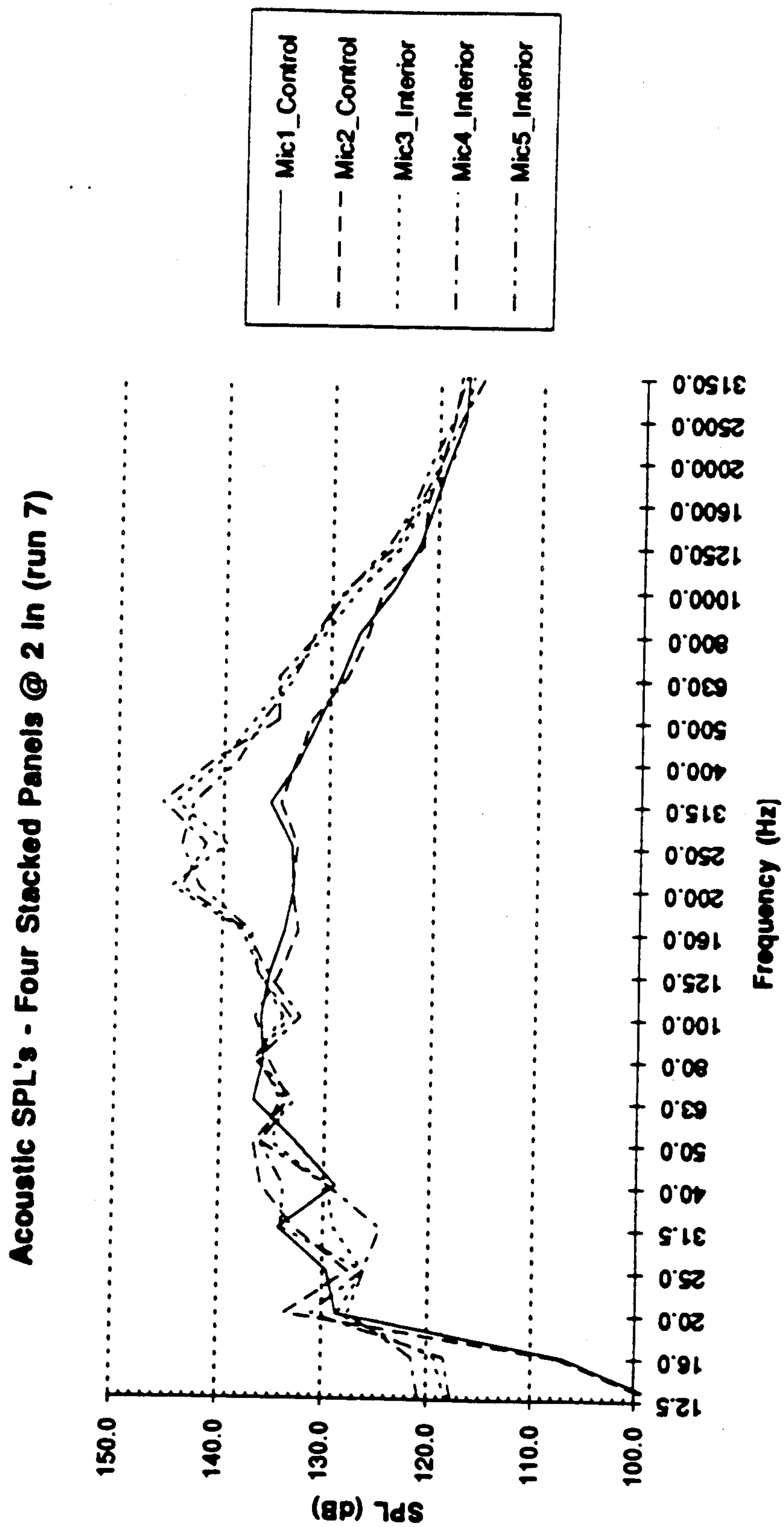



Acoustic SPL's - Four Stacked Panels @ 2 in (run 6)
Mic1_Control
Mic2_Control
Mic3_Interior
Mic4_Interior
Mic5_Interior
SPL (dB)
150.0
140.0
130.0
120.0
110.0
100.0
Frequency (Hz)
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0


Quarter-Panel Narrow Band Data
Four Panels Stacked 2 in. Apart (run 6)
a1-r6
bad chan. 2
a3-r6
a4-r6
a5-r6
a6-r6
a7-r6
a8-r6
100
10
1
0.1
0.01
0.001
PSD (G²/Hz)
10
100
1000
Frequency (Hz)

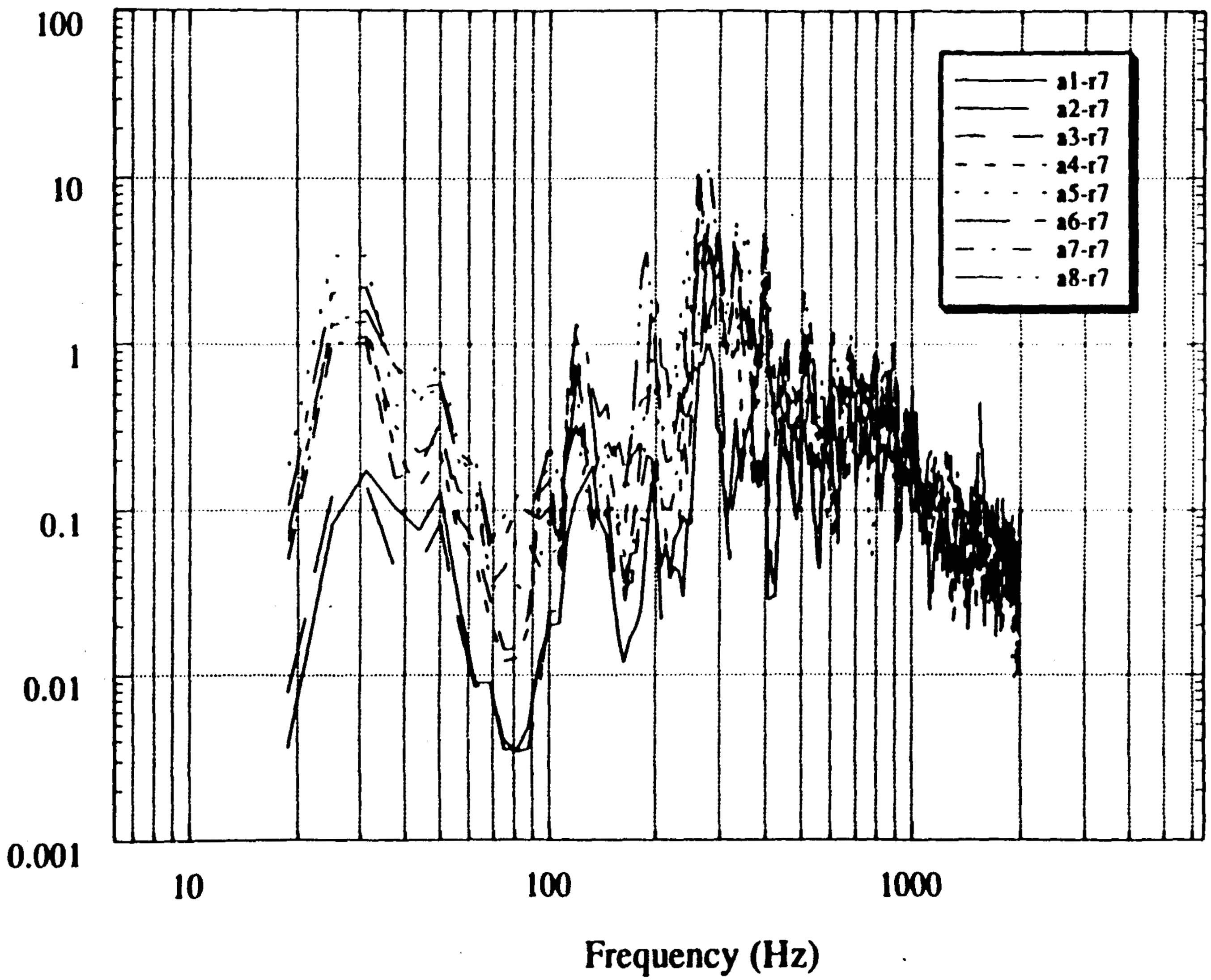
Quarter-Panel One-third Octave Band Data
Four Panels Stacked 2 in. Apart (run 6)

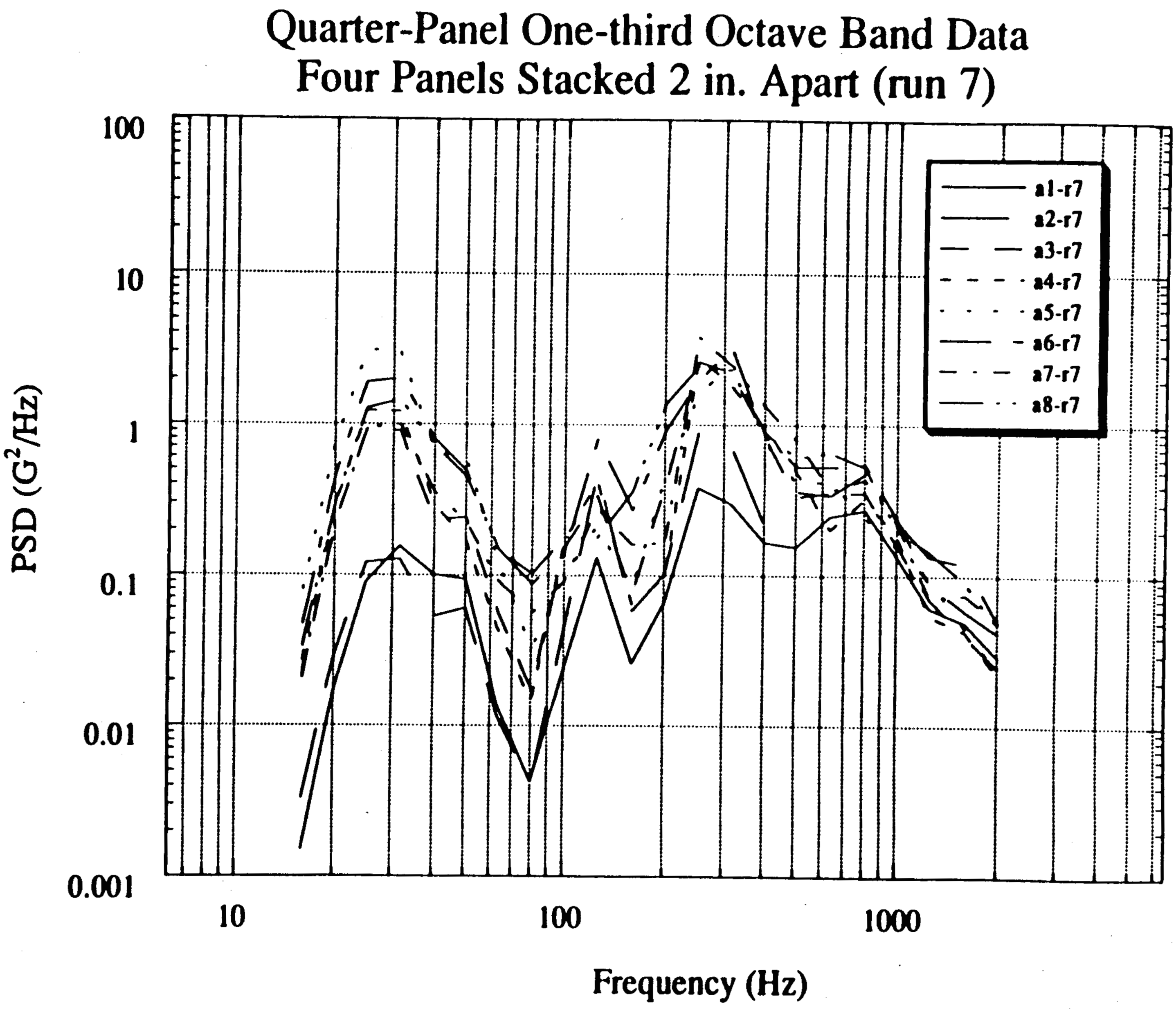


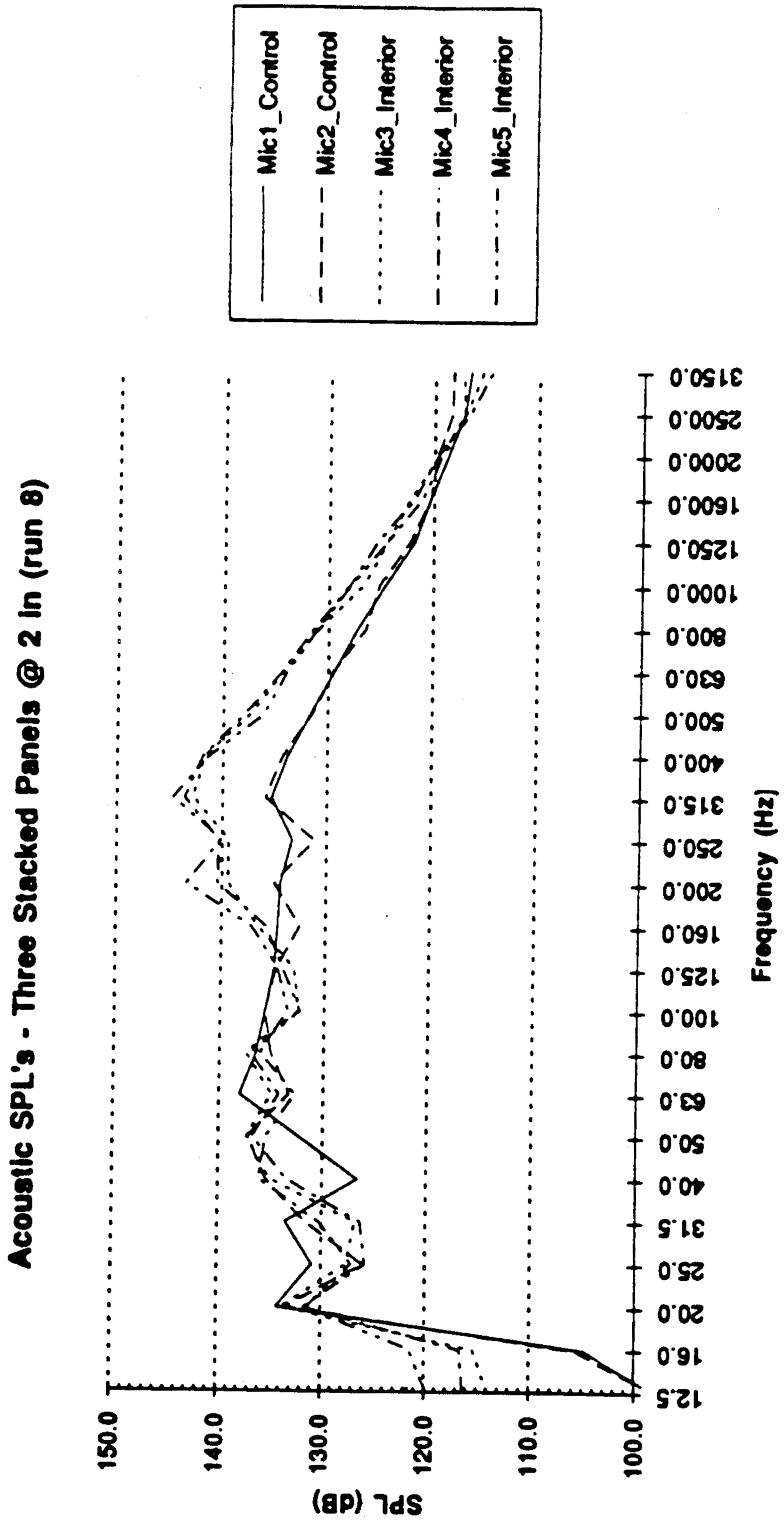


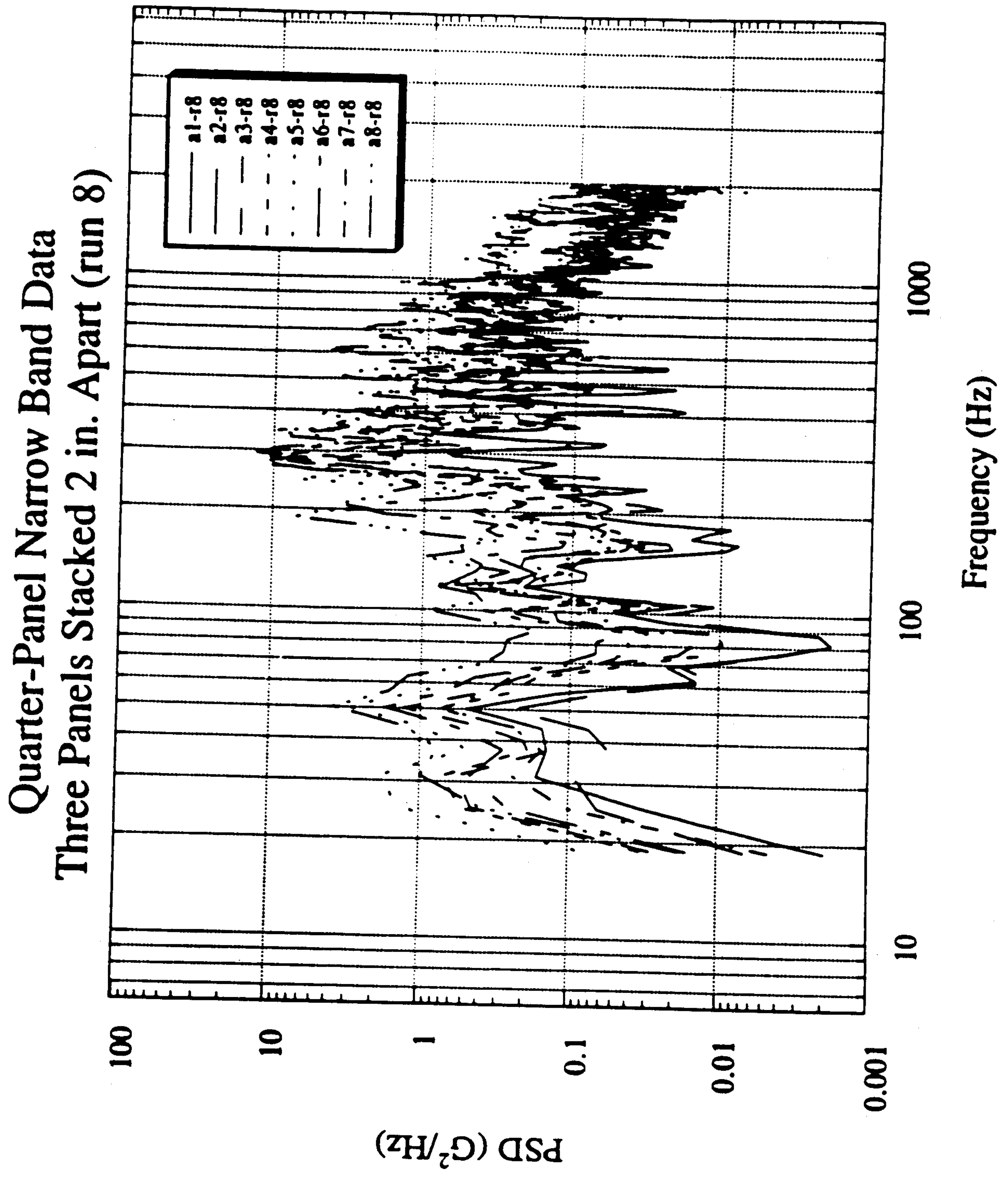
Acoustic SPL's - Four Stacked Panels @ 2 In (run 7)
Mic1_Control
Mic2_Control
Mic3_Interior
Mic4_Interior
Mic5_Interior
SPL (dB)
150.0
140.0
130.0
120.0
110.0
100.0
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0
Frequency (Hz)

Quarter-Panel Narrow Band Data
Four Panels Stacked 2 in. Apart (run 7)

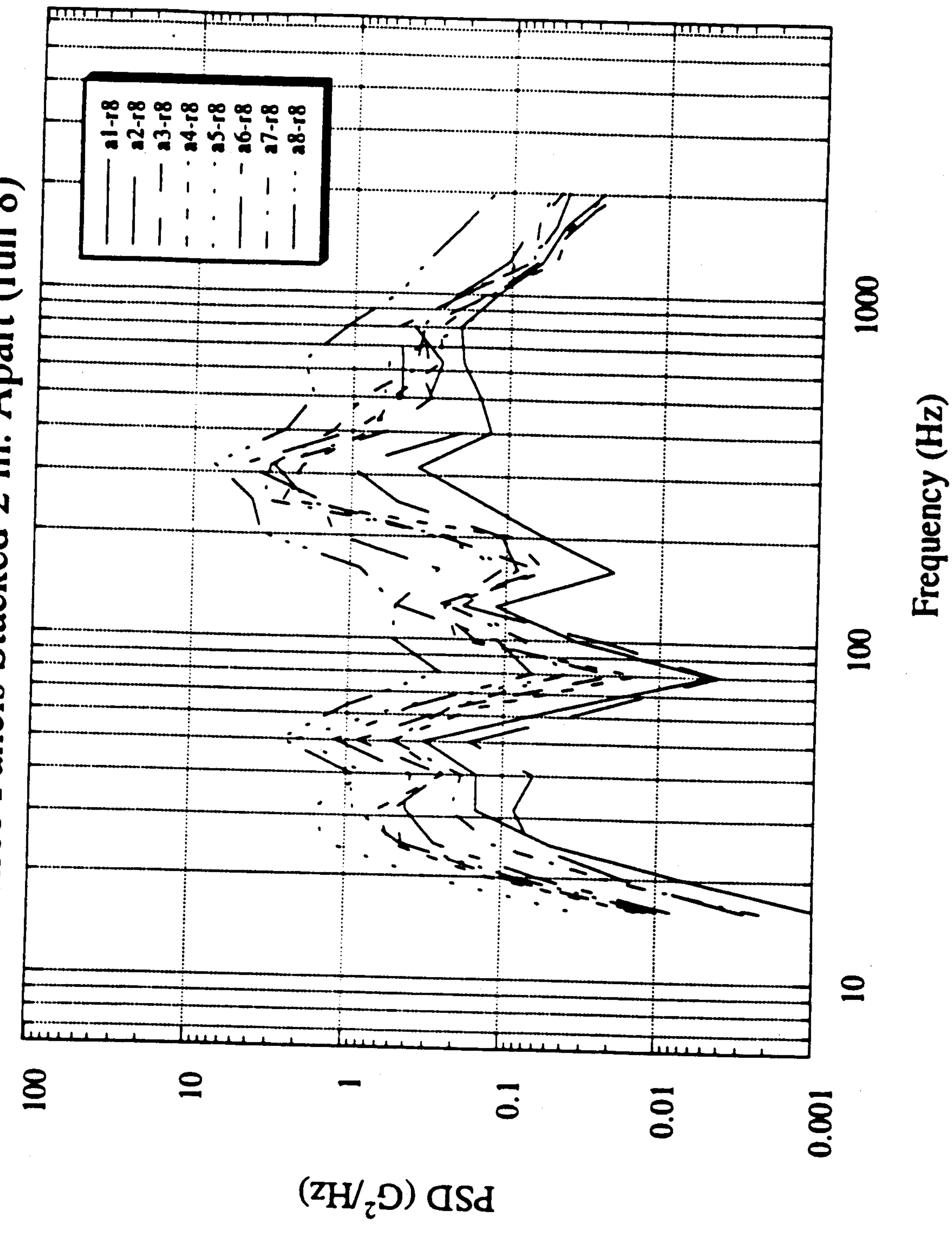



Quarter-Panel One-third Octave Band Data
Four Panels Stacked 2 in. Apart (run 7)
PSD (G²/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)
a1-r7
a2-r7
a3-r7
a4-r7
a5-r7
a6-r7
a7-r7
a8-r7

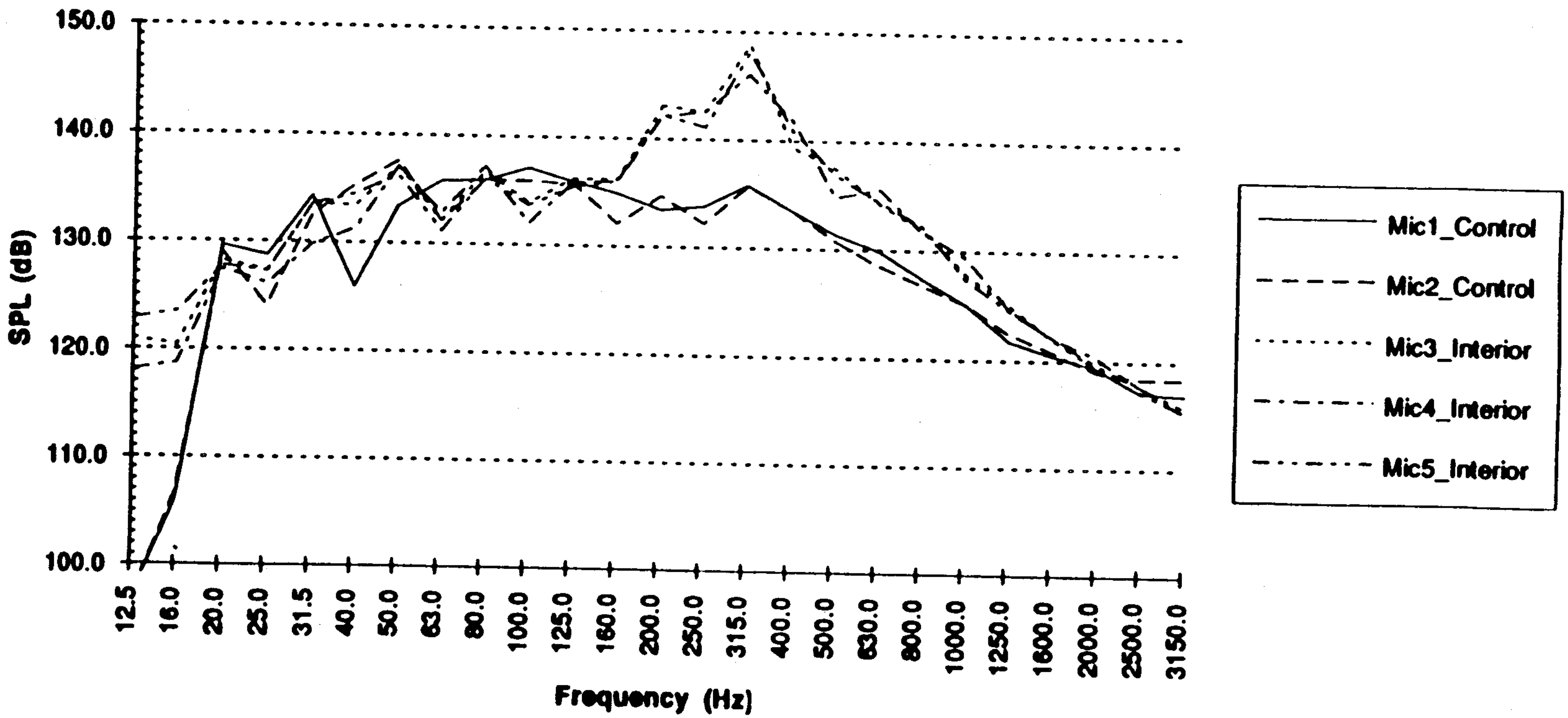

Acoustic SPL's - Three Stacked Panels @ 2 in (run 8)
Mic1_Control
Mic2_Control
Mic3_Interior
Mic4_Interior
Mic5_Interior
SPL (dB)
150.0
140.0
130.0
120.0
110.0
100.0
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0
Frequency (Hz)

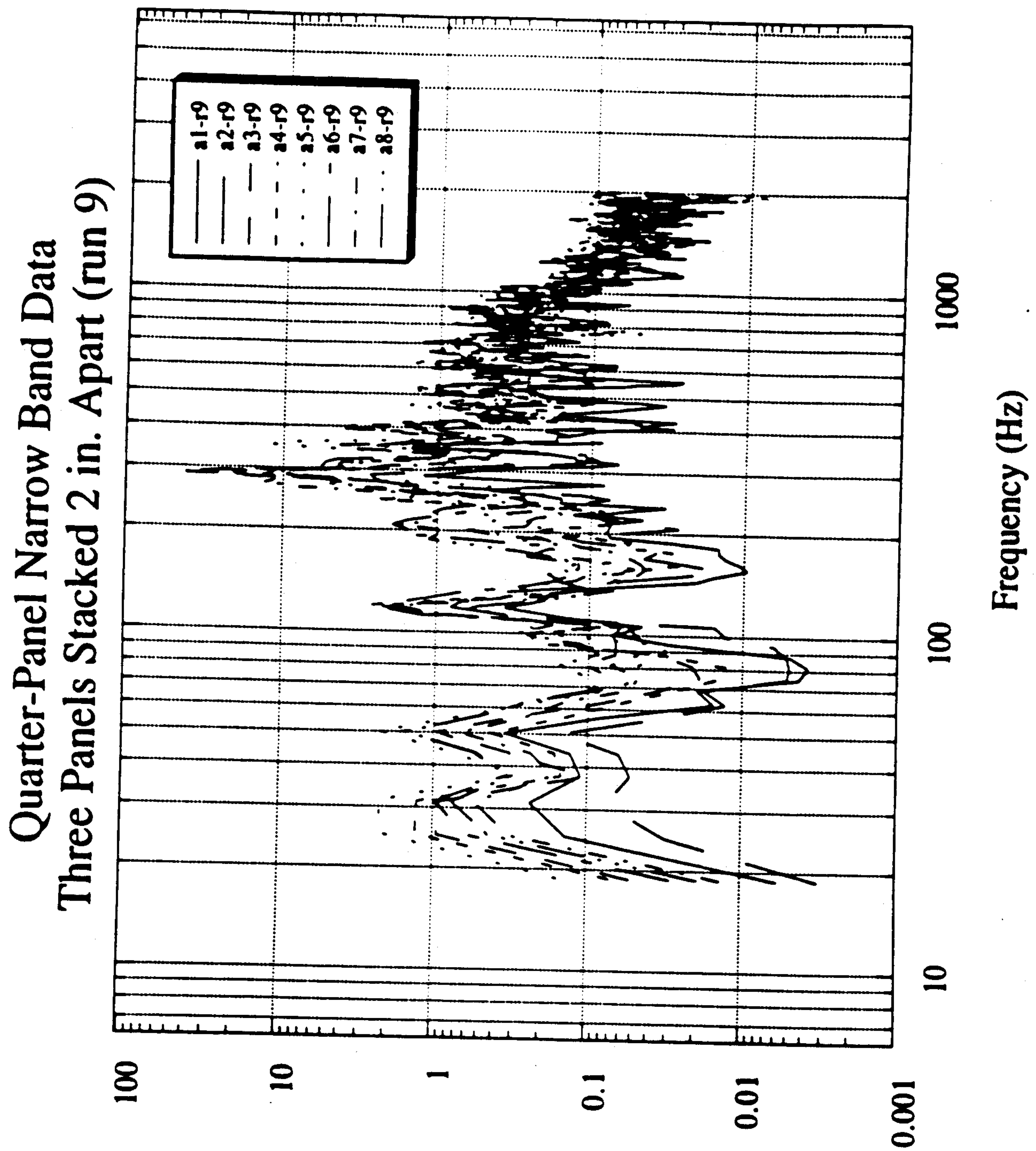

Quarter-Panel Narrow Band Data
Three Panels Stacked 2 in. Apart (run 8)
a1-r8
a2-r8
a3-r8
a4-r8
a5-r8
a6-r8
a7-r8
a8-r8
100
10
1
0.1
0.01
0.001
PSD (G^2/Hz)
10
100
1000
Frequency (Hz)

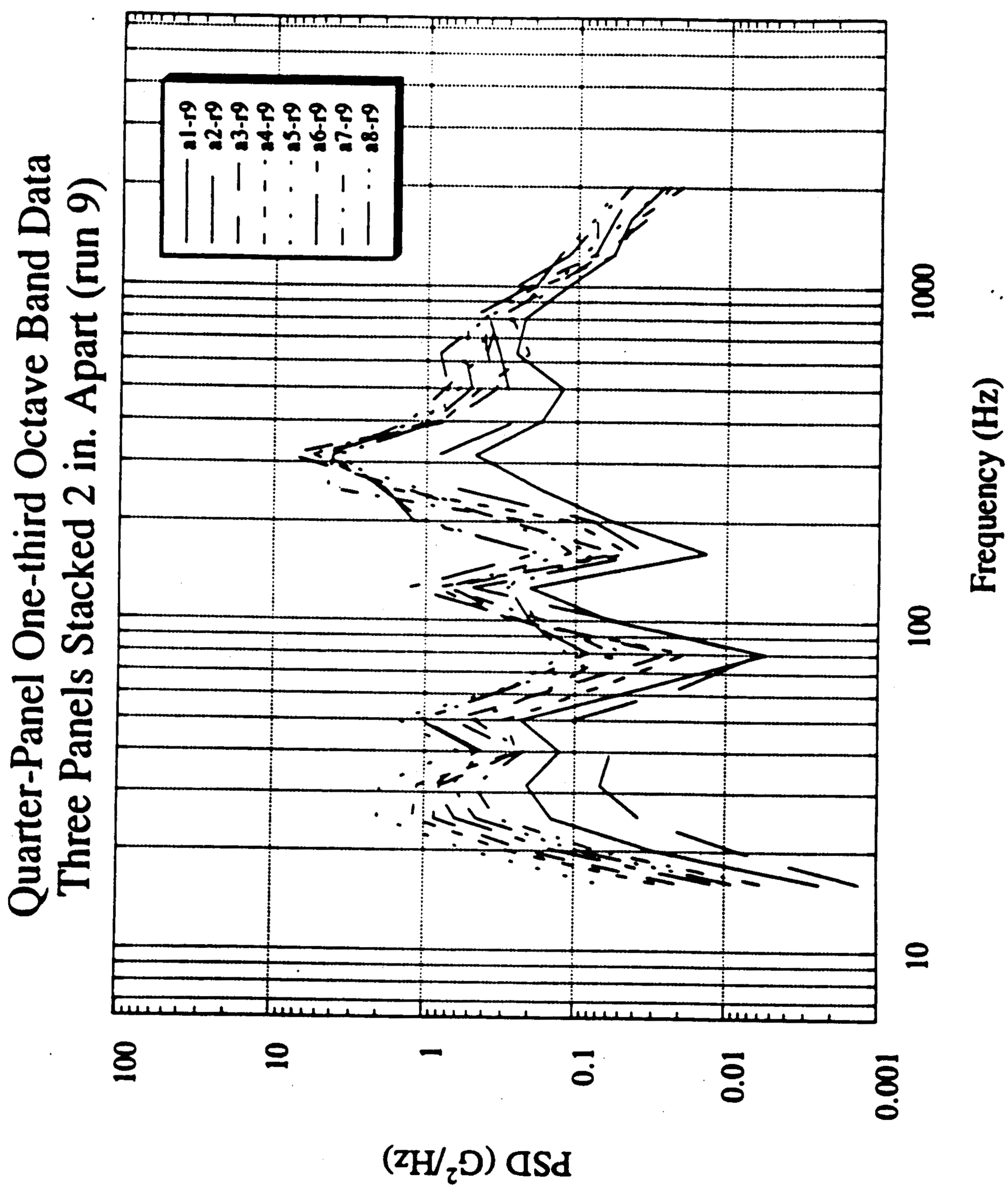
Quarter-Panel One-third Octave Band Data
Three Panels Stacked 2 in. Apart (run 8)



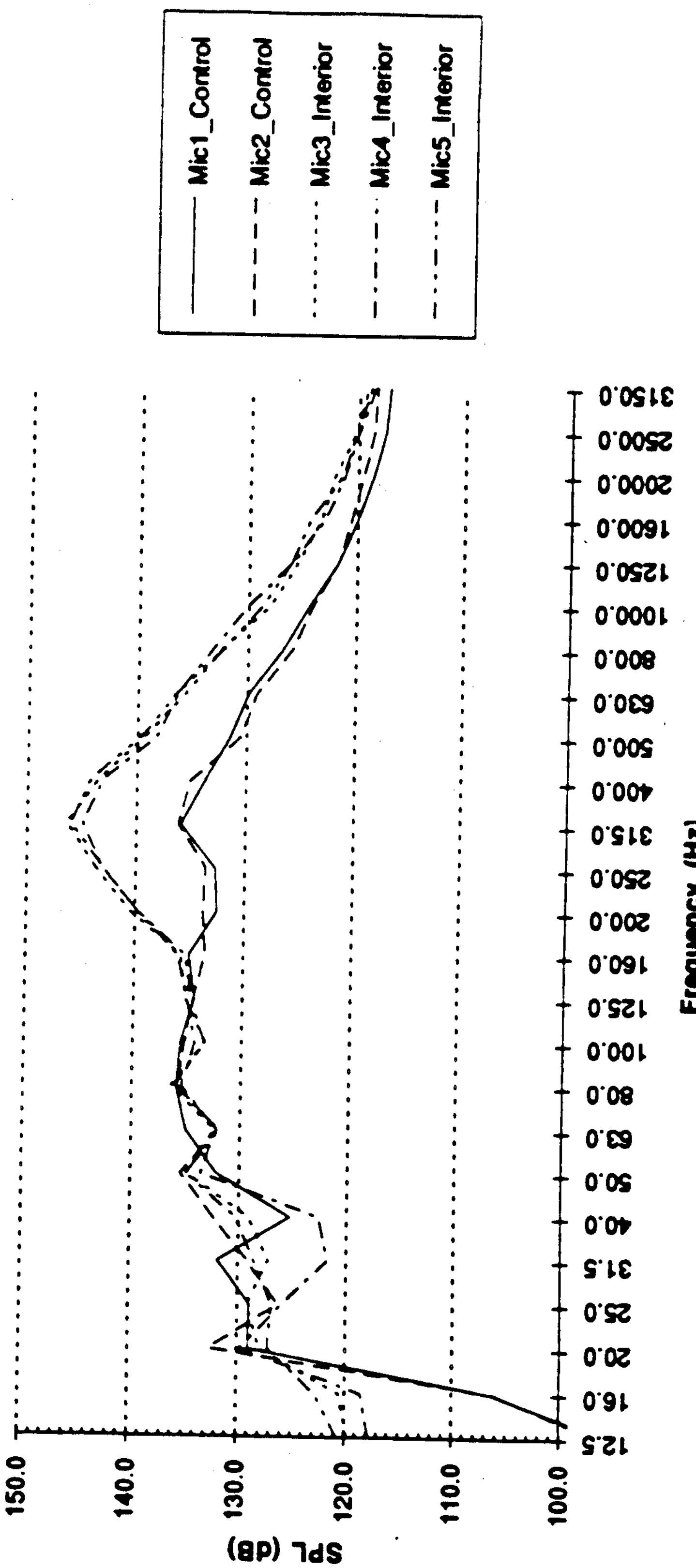
Acoustic SPL's - Three Stacked Panels @ 2 in (run 9)

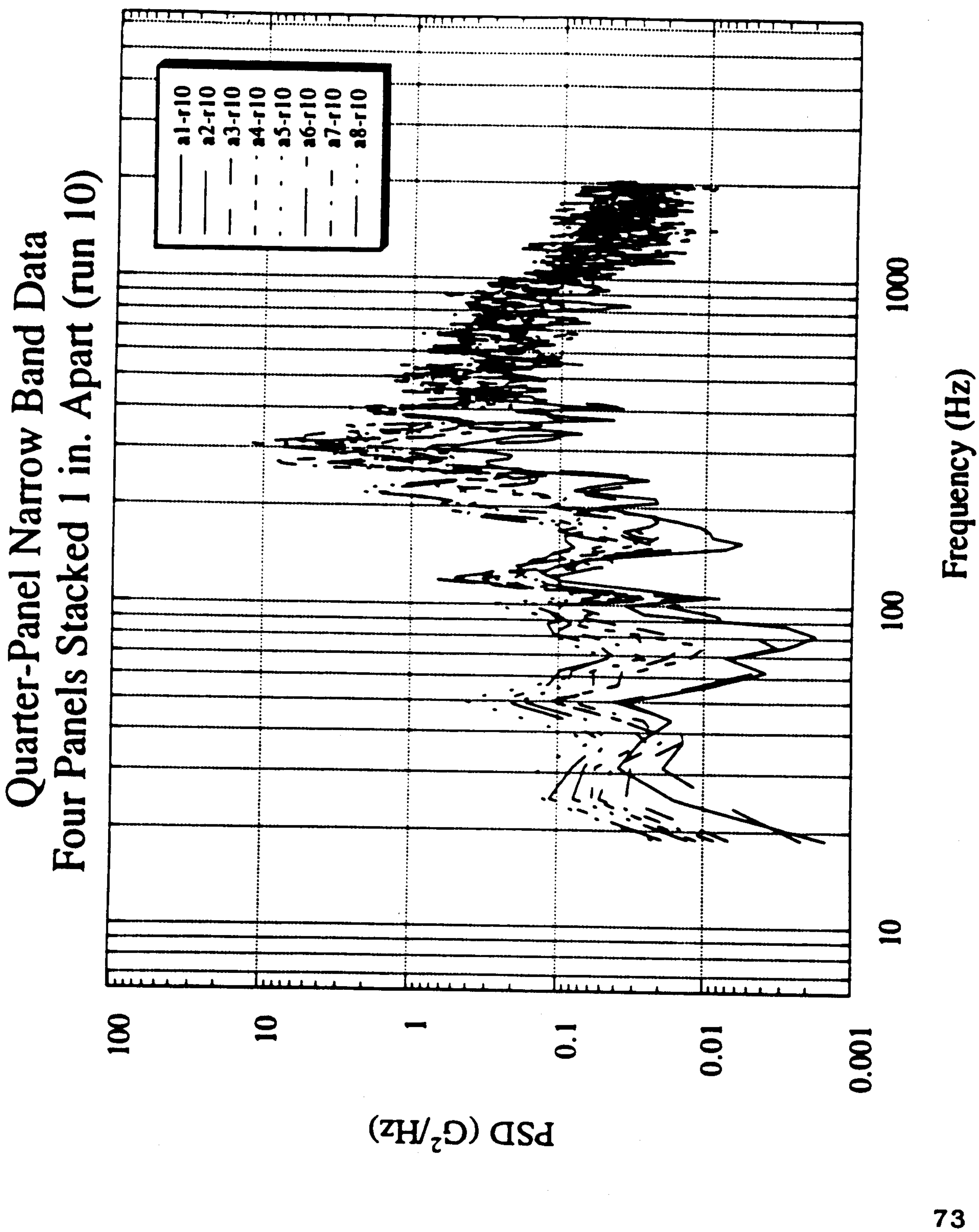


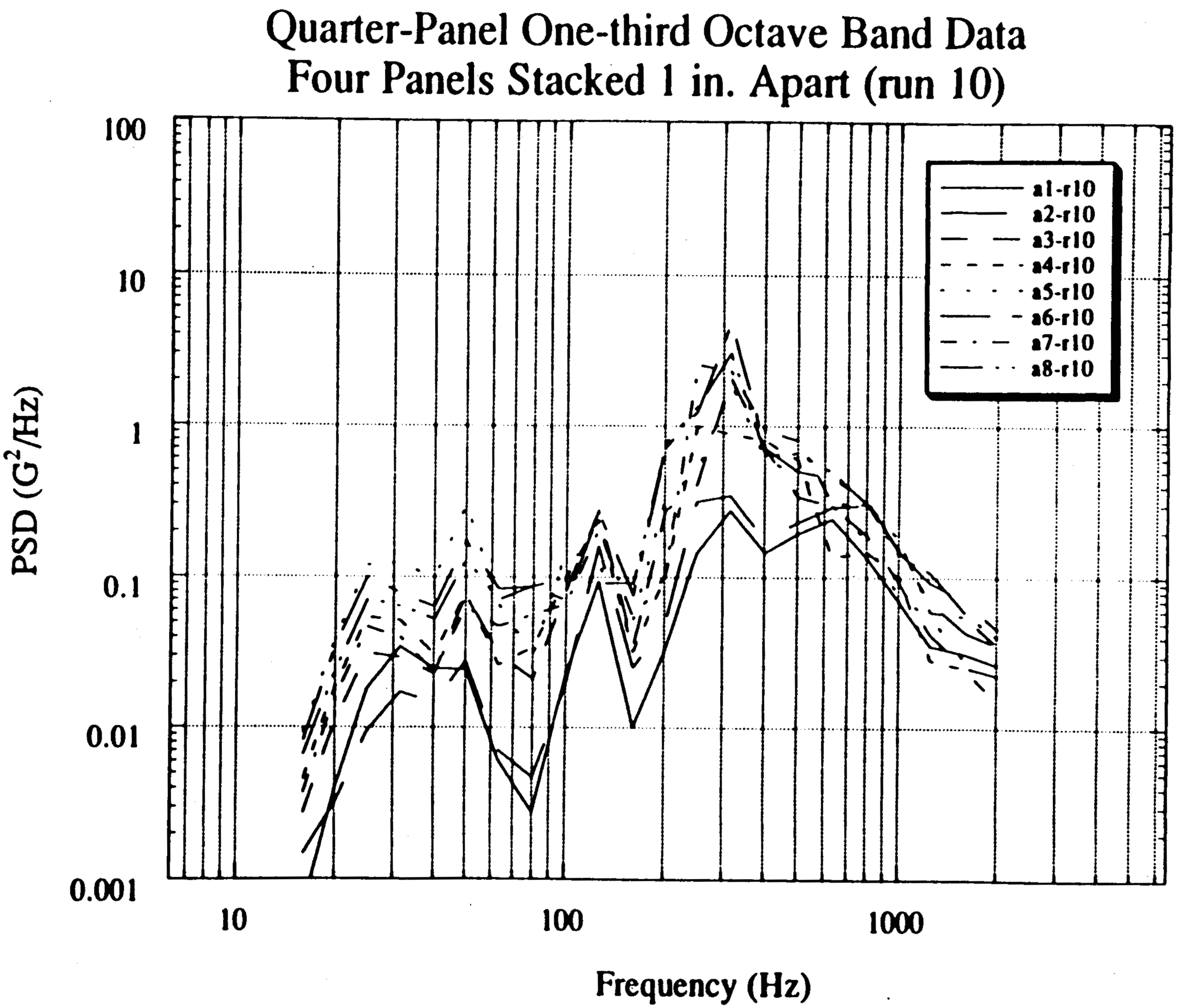

Quarter-Panel Narrow Band Data
Three Panels Stacked 2 in. Apart (run 9)
a1-r9
a2-r9
a3-r9
a4-r9
a5-r9
a6-r9
a7-r9
a8-r9
100
10
1
0.1
0.01
0.001
PSD (G²/Hz)
10
100
1000
Frequency (Hz)


Quarter-Panel One-third Octave Band Data
Three Panels Stacked 2 in. Apart (run 9)
a1-r9
a2-r9
a3-r9
a4-r9
a5-r9
a6-r9
a7-r9
a8-r9
PSD (G²/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)

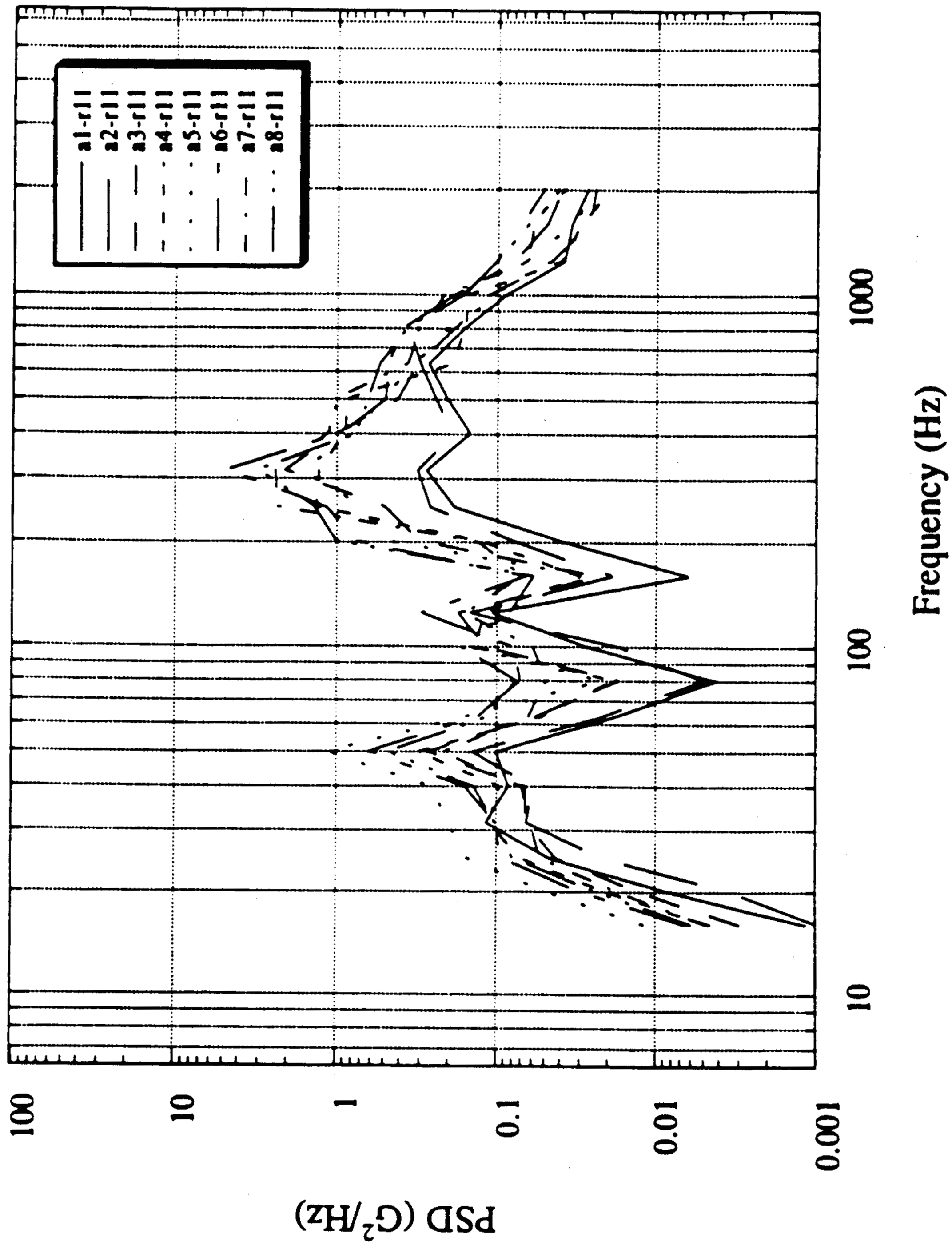
Acoustic SPL's - Four Stacked Panels @ 1 in (run 10)

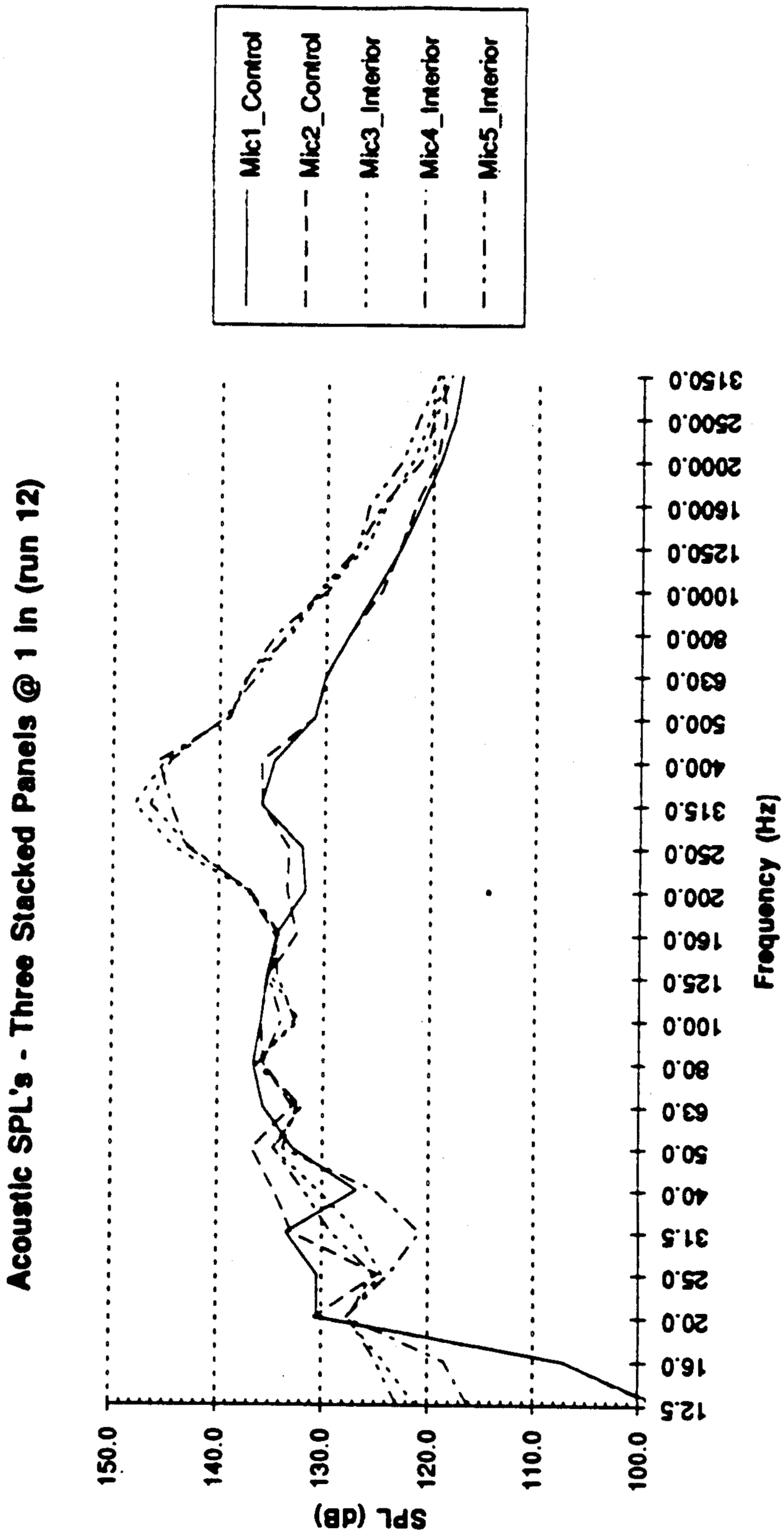



Quarter-Panel Narrow Band Data
Four Panels Stacked 1 in. Apart (run 10)
a1-r10
a2-r10
a3-r10
a4-r10
a5-r10
a6-r10
a7-r10
a8-r10
PSD (G²/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)

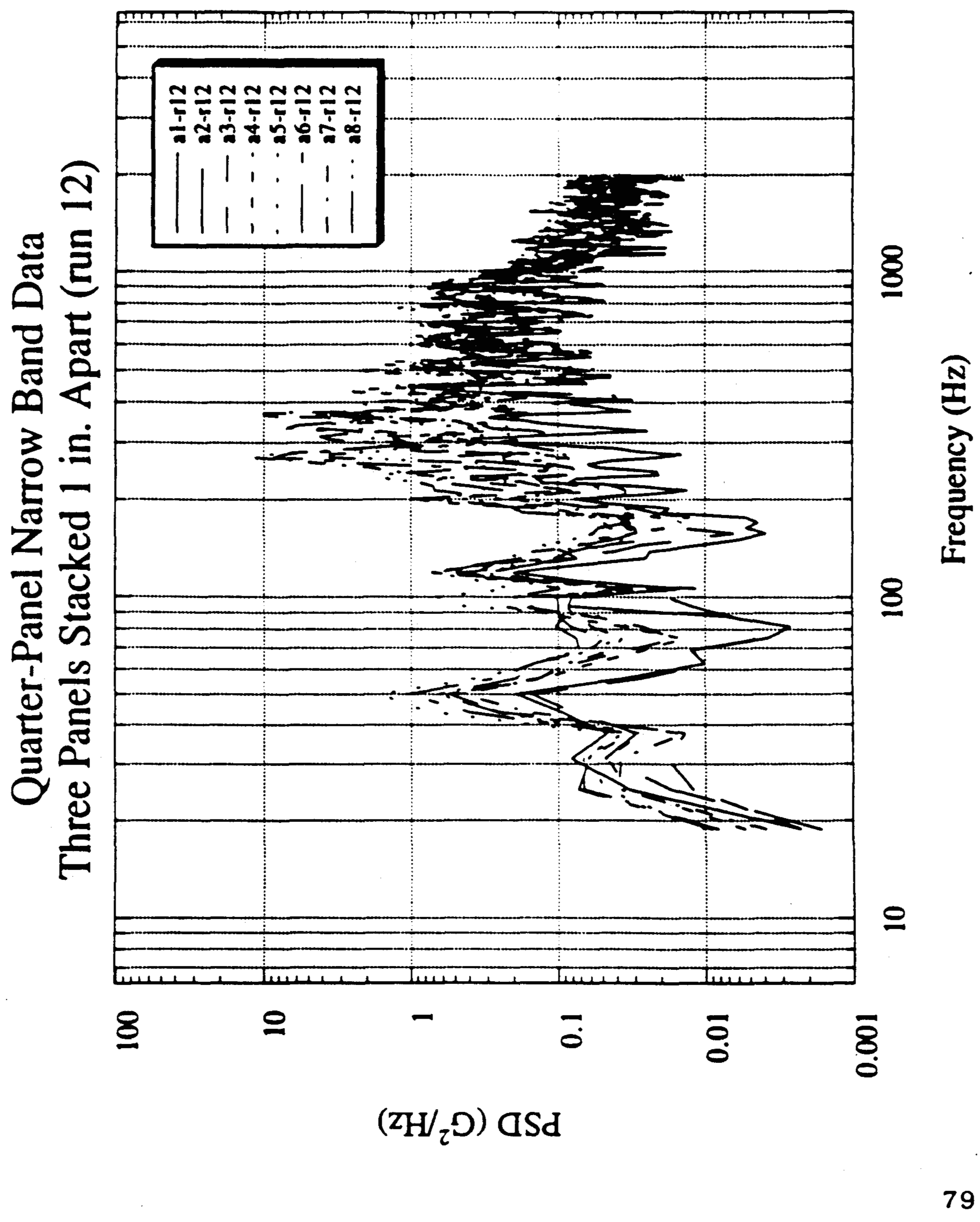

Quarter-Panel One-third Octave Band Data
Four Panels Stacked 1 in. Apart (run 10)
PSD (G^2/Hz)
100
10
1
0.1
0.01
0.001
10
100
1000
Frequency (Hz)
a1-r10
a2-r10
a3-r10
a4-r10
a5-r10
a6-r10
a7-r10
a8-r10

Quarter-Panel One-third Octave Band Data
Four Panels Stacked 1 in. Apart (run 11)

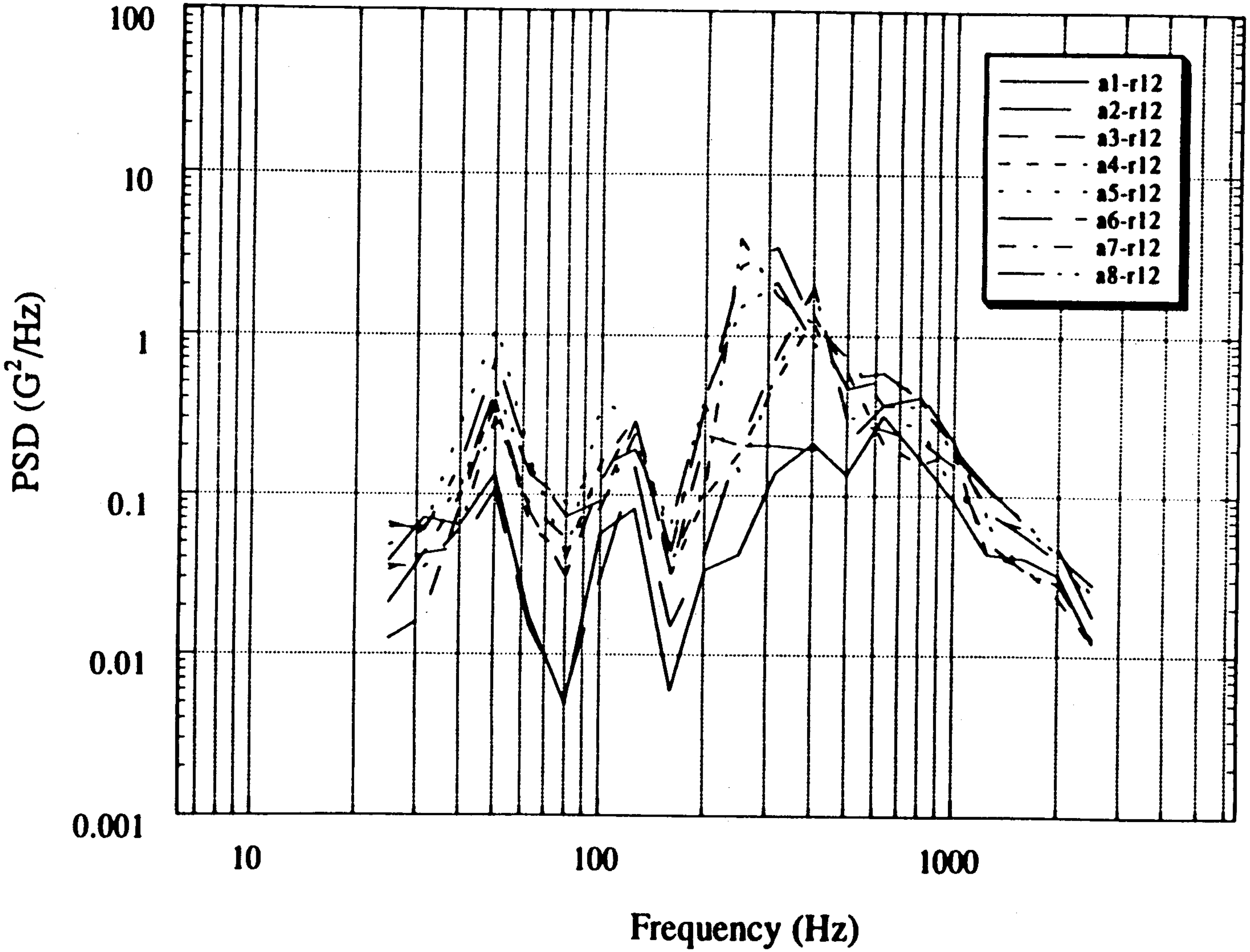


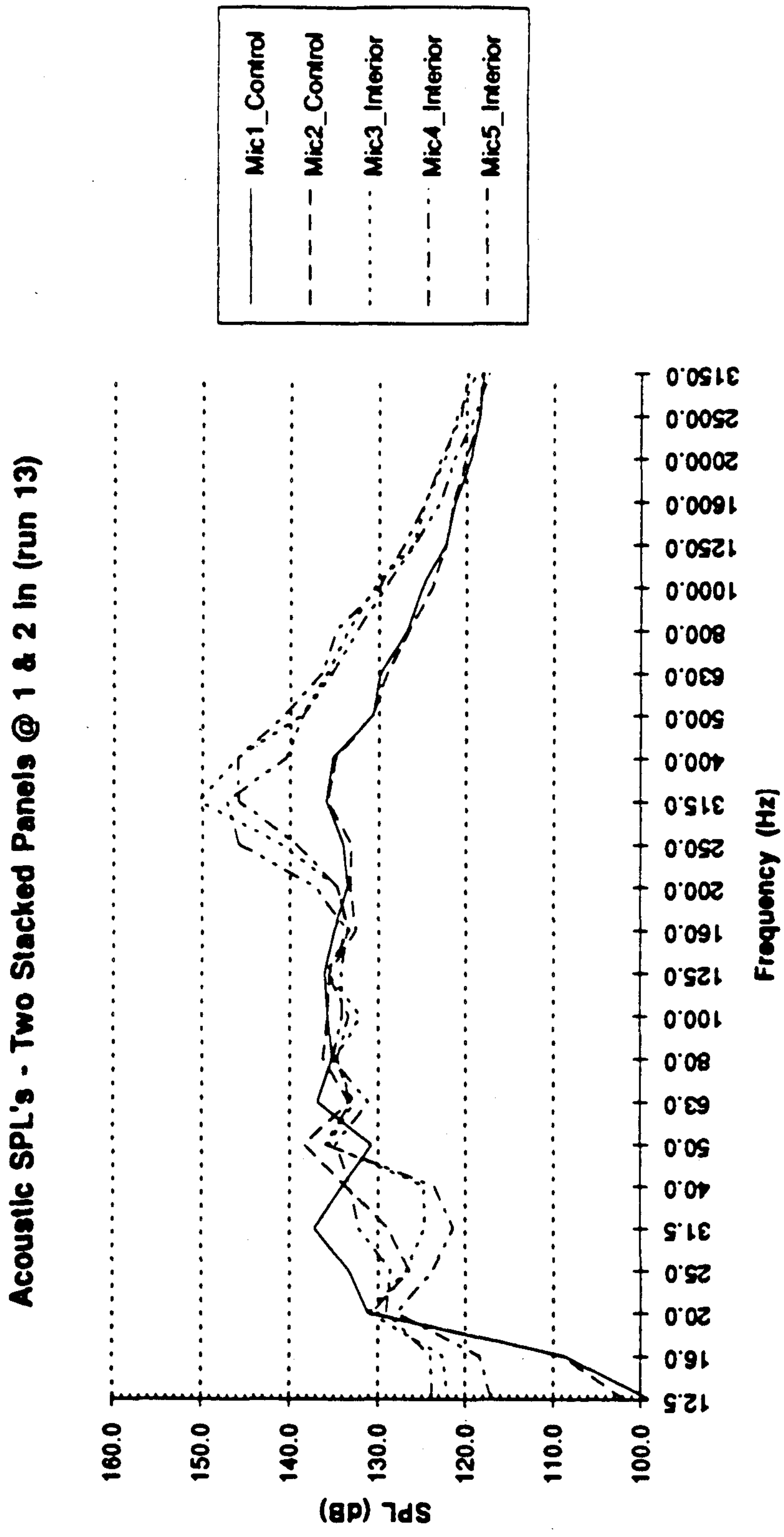


Acoustic SPL's - Three Stacked Panels @ 1 in (run 12)
Mic1_Control
Mic2_Control
Mic3_Interior
Mic4_Interior
Mic5_Interior
SPL (dB)
150.0
140.0
130.0
120.0
110.0
100.0
Frequency (Hz)
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0

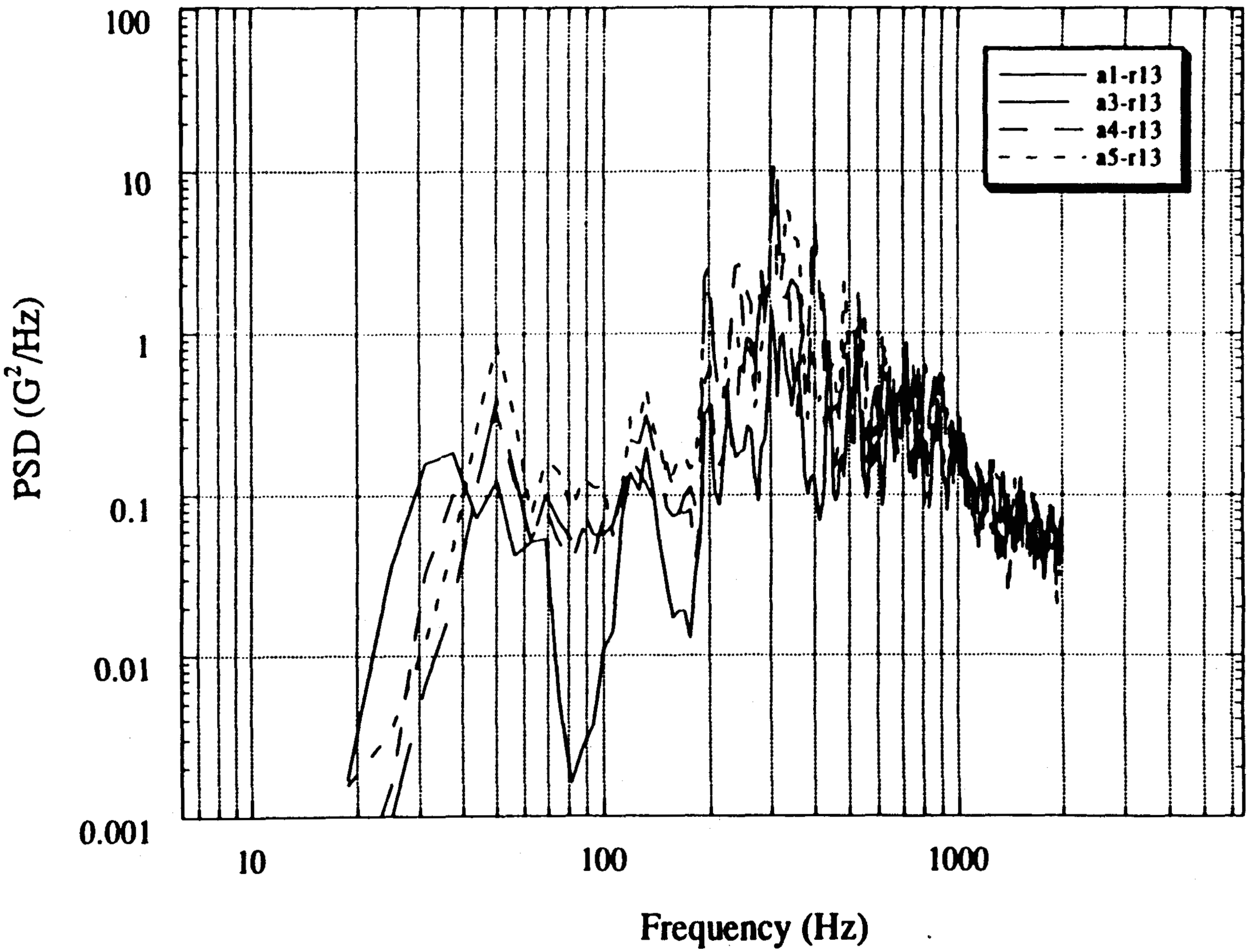

Quarter-Panel Narrow Band Data
Three Panels Stacked 1 in. Apart (run 12)
a1-r12
a2-r12
a3-r12
a4-r12
a5-r12
a6-r12
a7-r12
a8-r12
100
10
1
0.1
0.01
0.001
PSD (G²/Hz)
10
100
1000
Frequency (Hz)

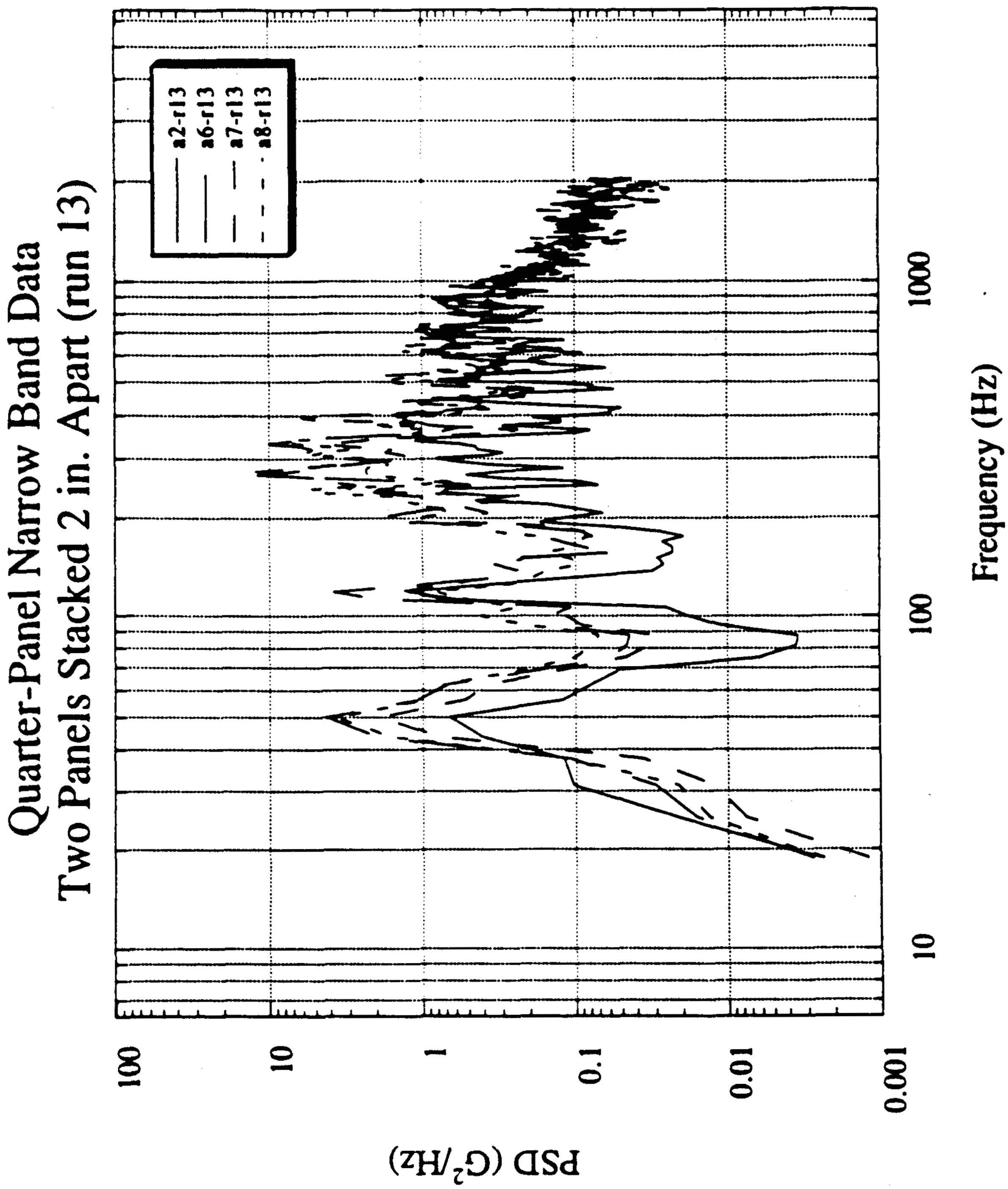
Quarter-Panel One-third Octave Band Data
Three Panels Stacked 1 in. Apart (run 12)



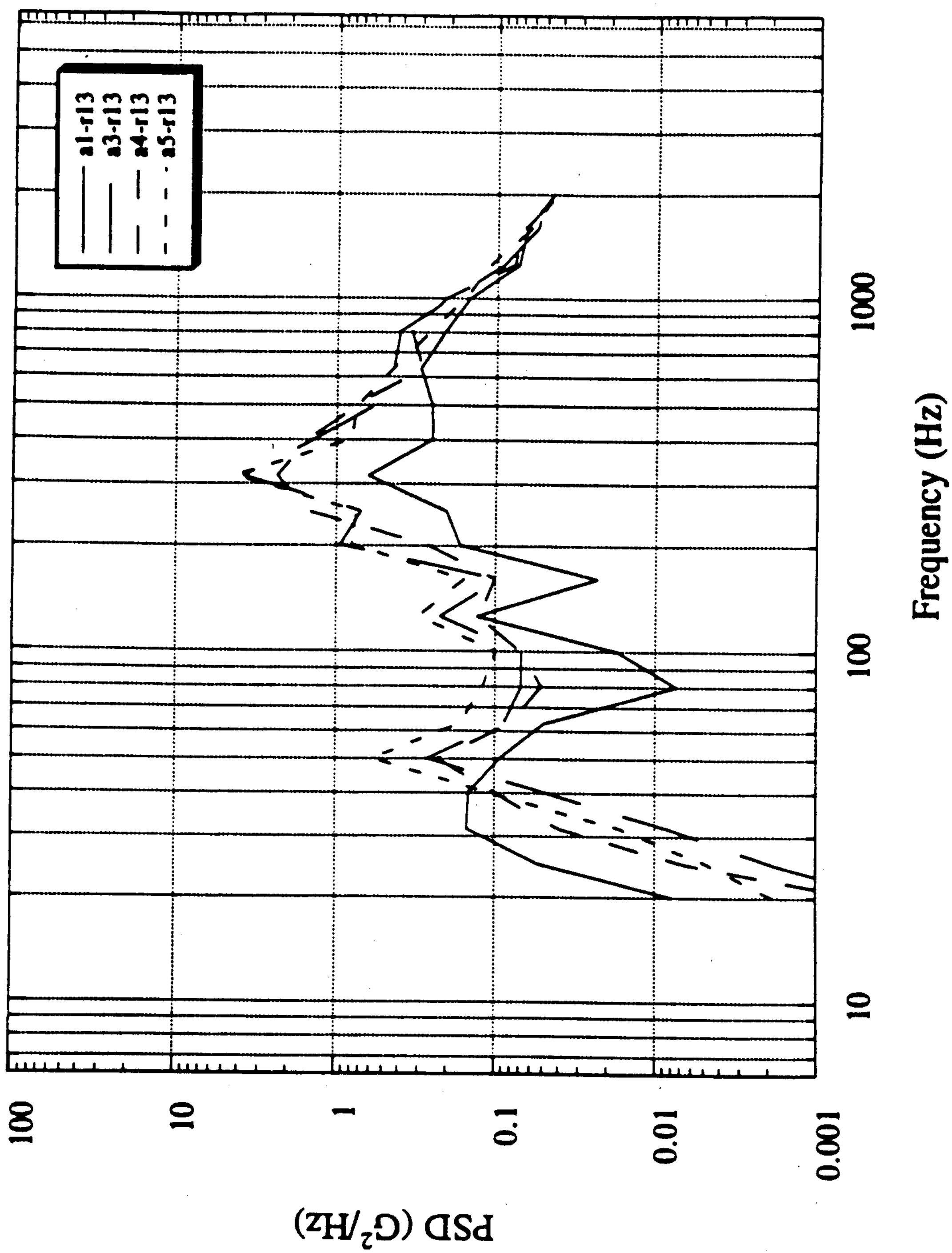

Acoustic SPL's - Two Stacked Panels @ 1 & 2 in (run 13)
SPL (dB)
160.0
150.0
140.0
130.0
120.0
110.0
100.0
12.5
16.0
20.0
25.0
31.5
40.0
50.0
63.0
80.0
100.0
125.0
160.0
200.0
250.0
315.0
400.0
500.0
630.0
800.0
1000.0
1250.0
1600.0
2000.0
2500.0
3150.0
Frequency (Hz)
Mic1_Control
Mic2_Control
Mic3_Interior
Mic4_Interior
Mic5_Interior

Quarter-Panel Narrow Band Data
Two Panels Stacked 1 in. Apart (run 13)

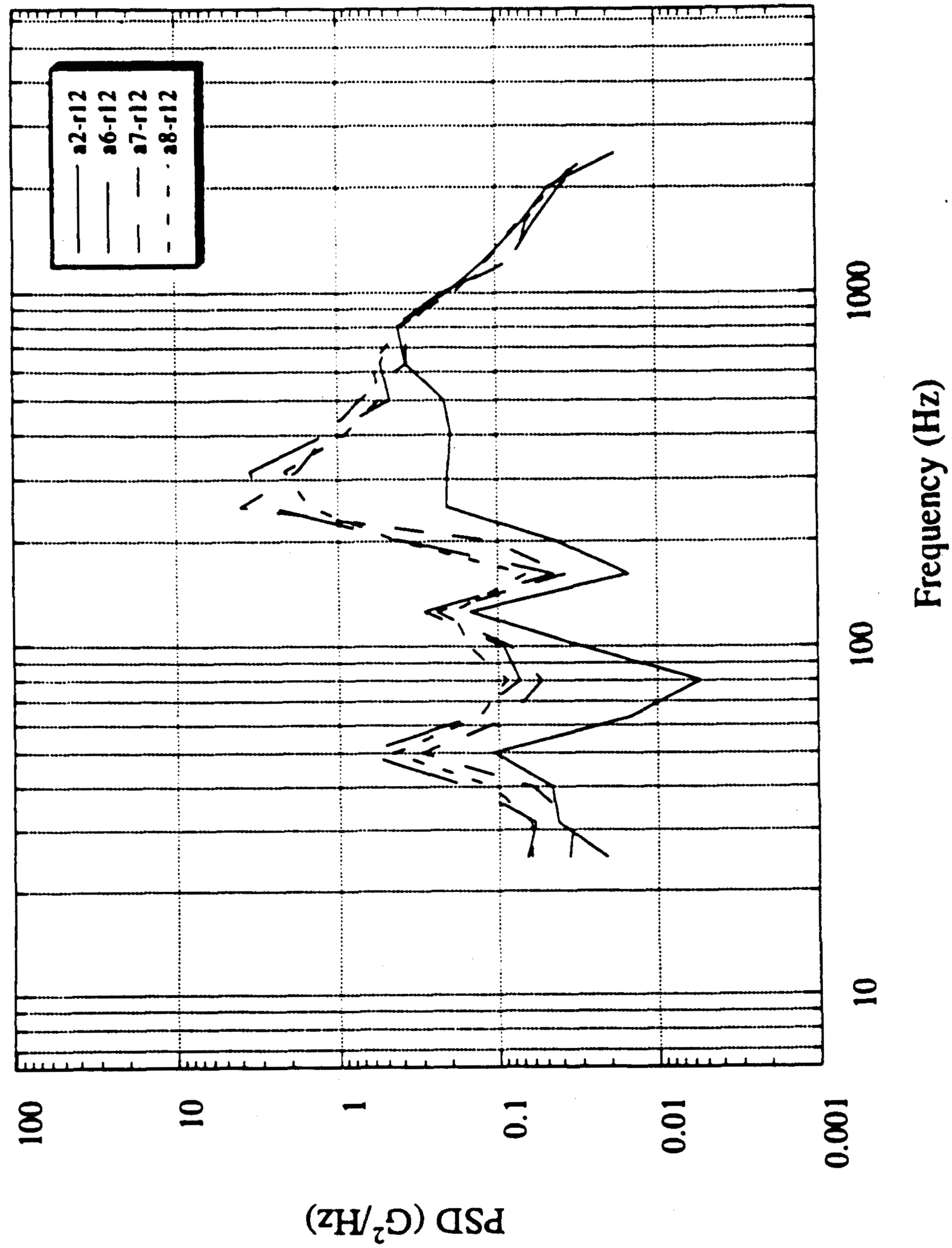



Quarter-Panel Narrow Band Data
Two Panels Stacked 2 in. Apart (run 13)
a2-r13
a6-r13
a7-r13
a8-r13
PSD (G²/Hz)
100
10
1
0.1
0.01
0.001
Frequency (Hz)
10
100
1000

Quarter-Panel One-third Octave Band Data
Two Panels Stacked 1 in. Apart (run 13)

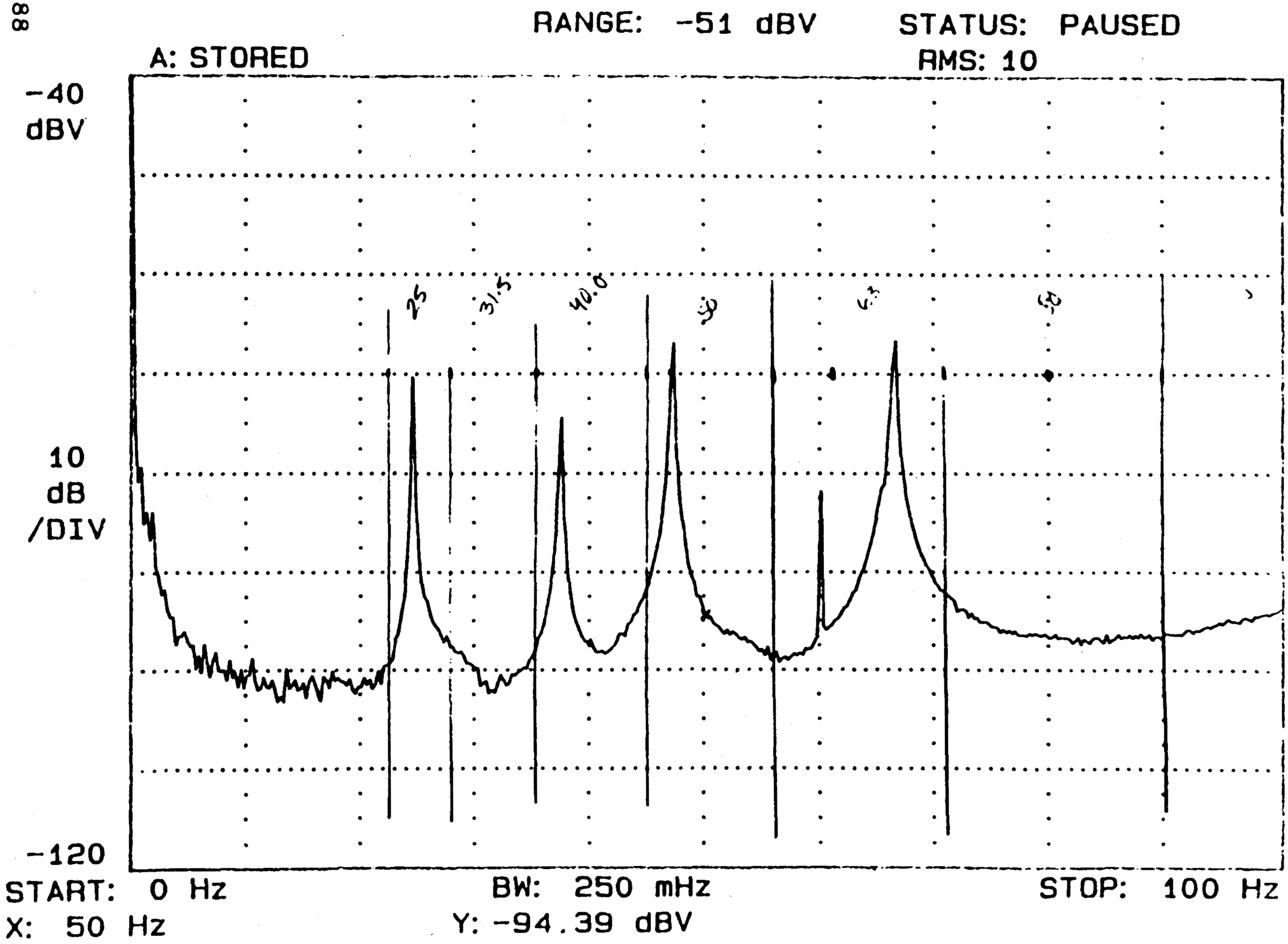


Quarter-Panel One-third Octave Band Data
Two Panels Stacked 2 in. Apart (run 13)

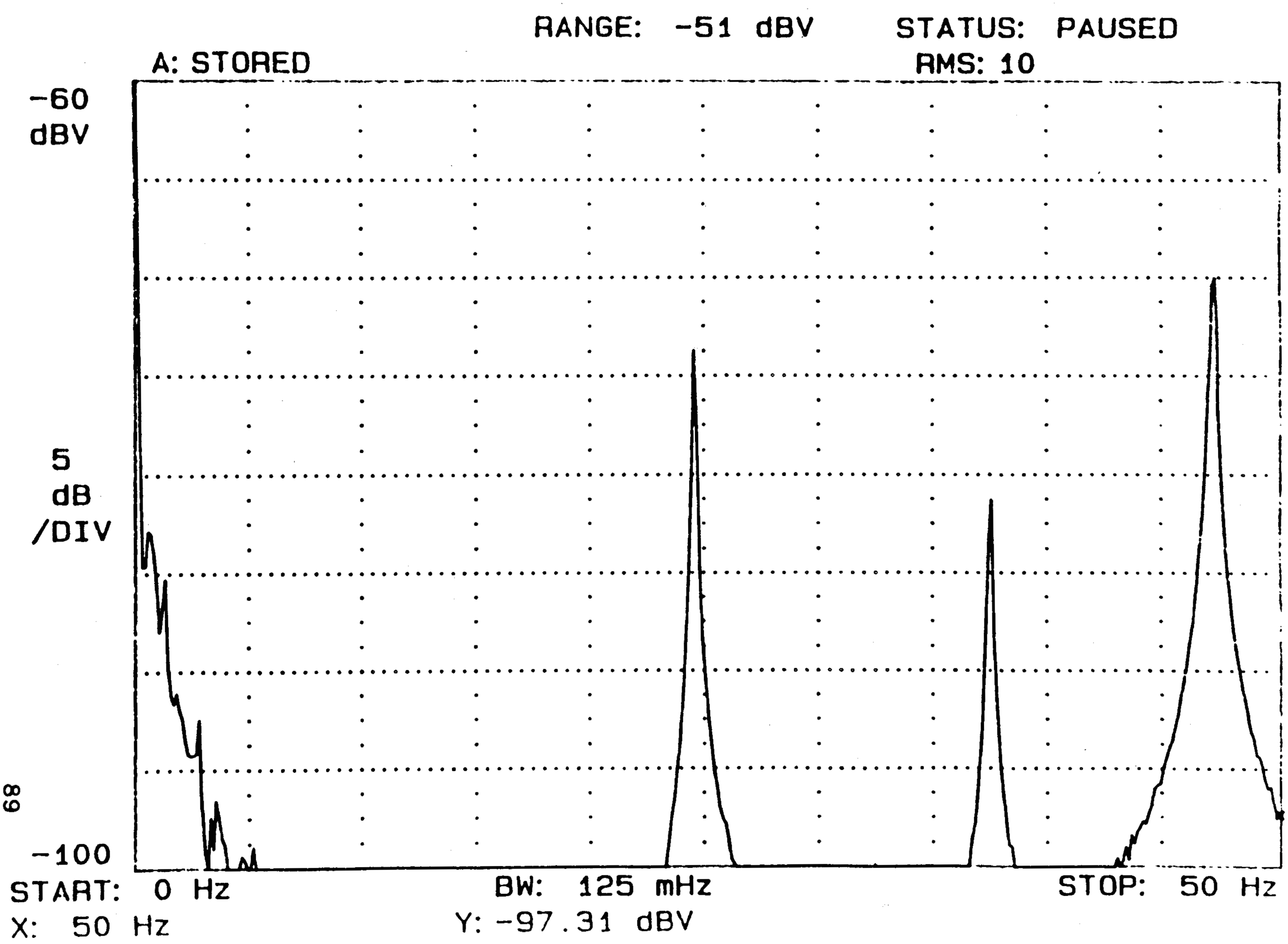


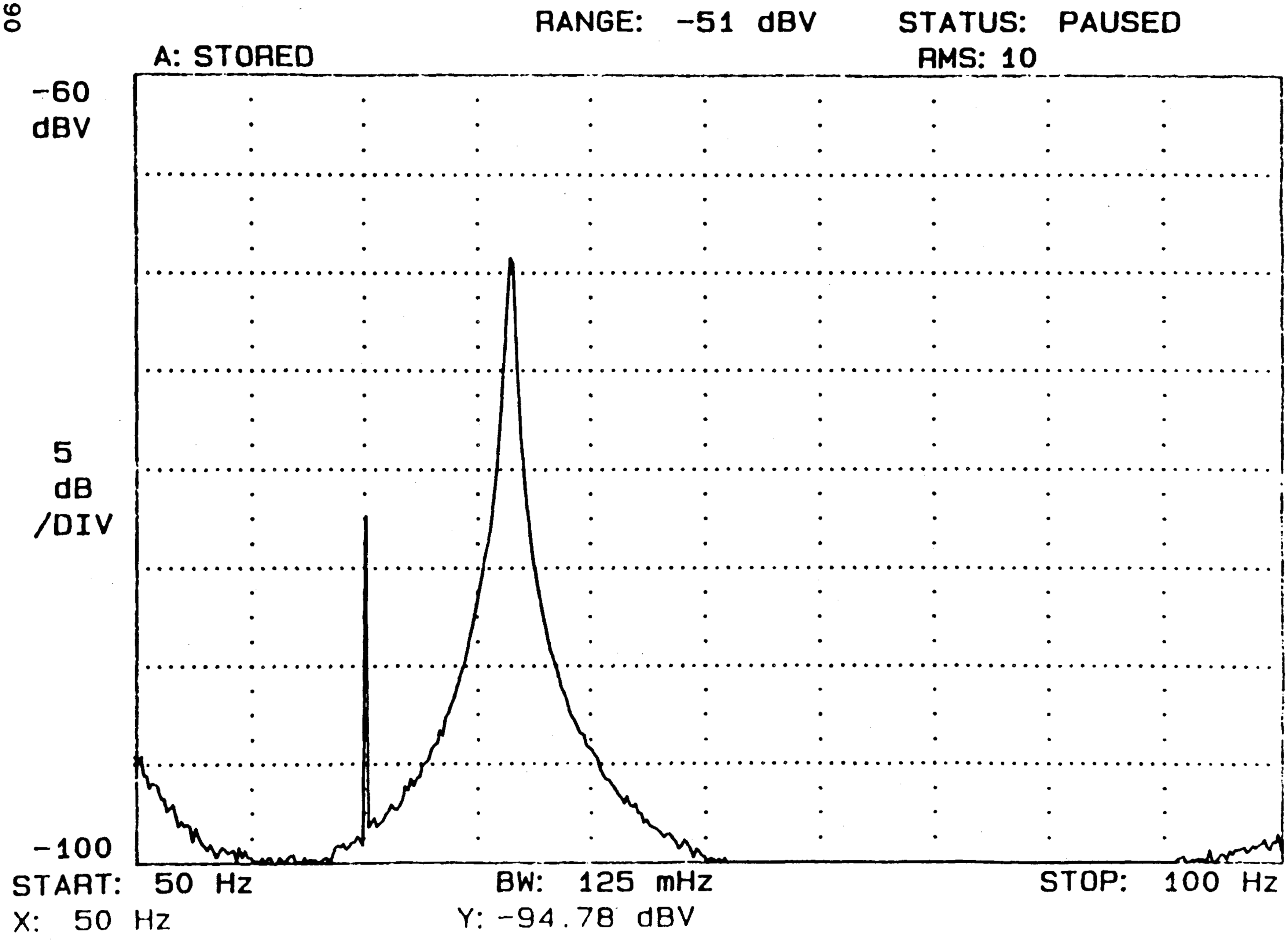
Appendix B:

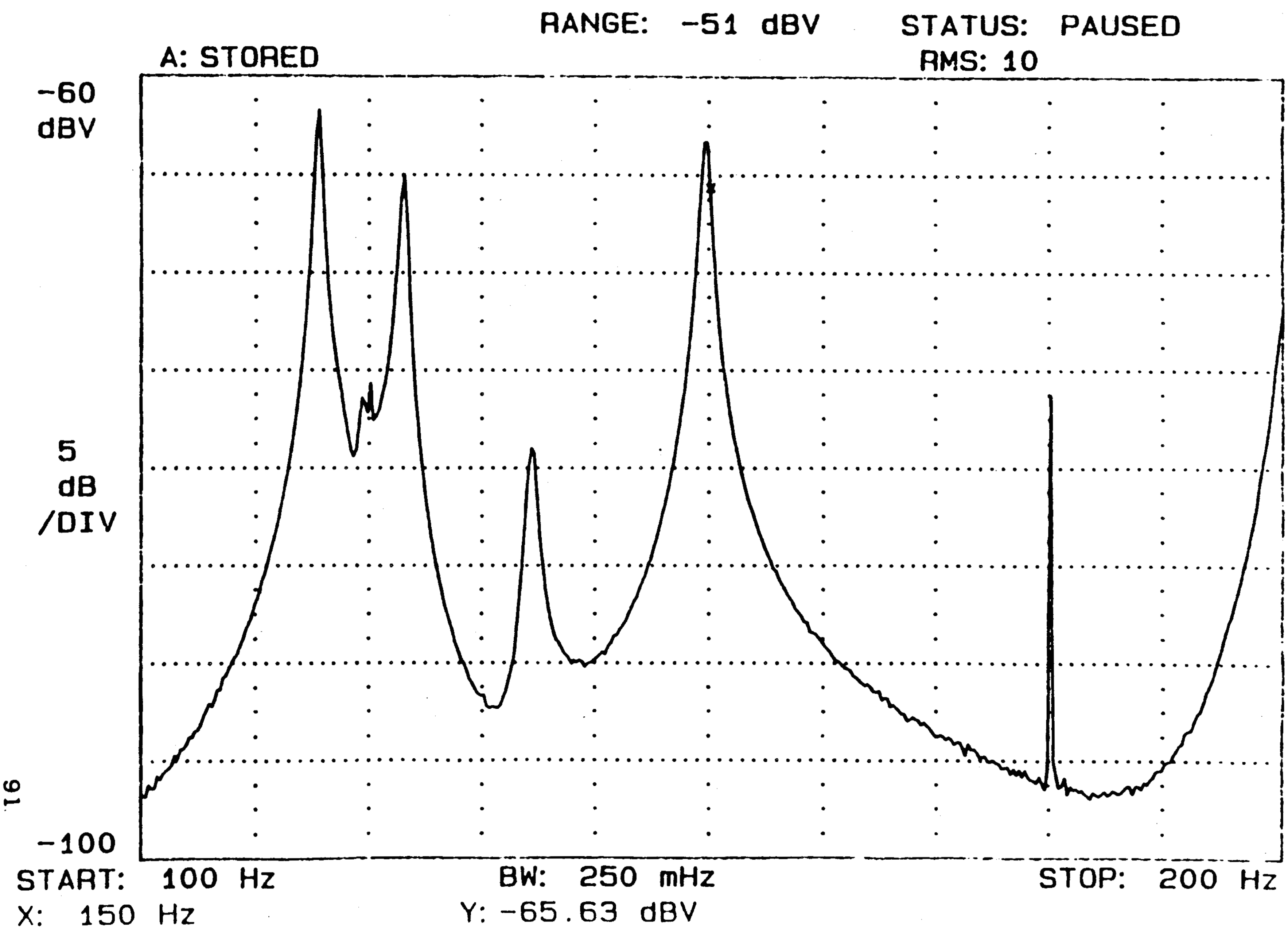
Panel Modal Response Plots

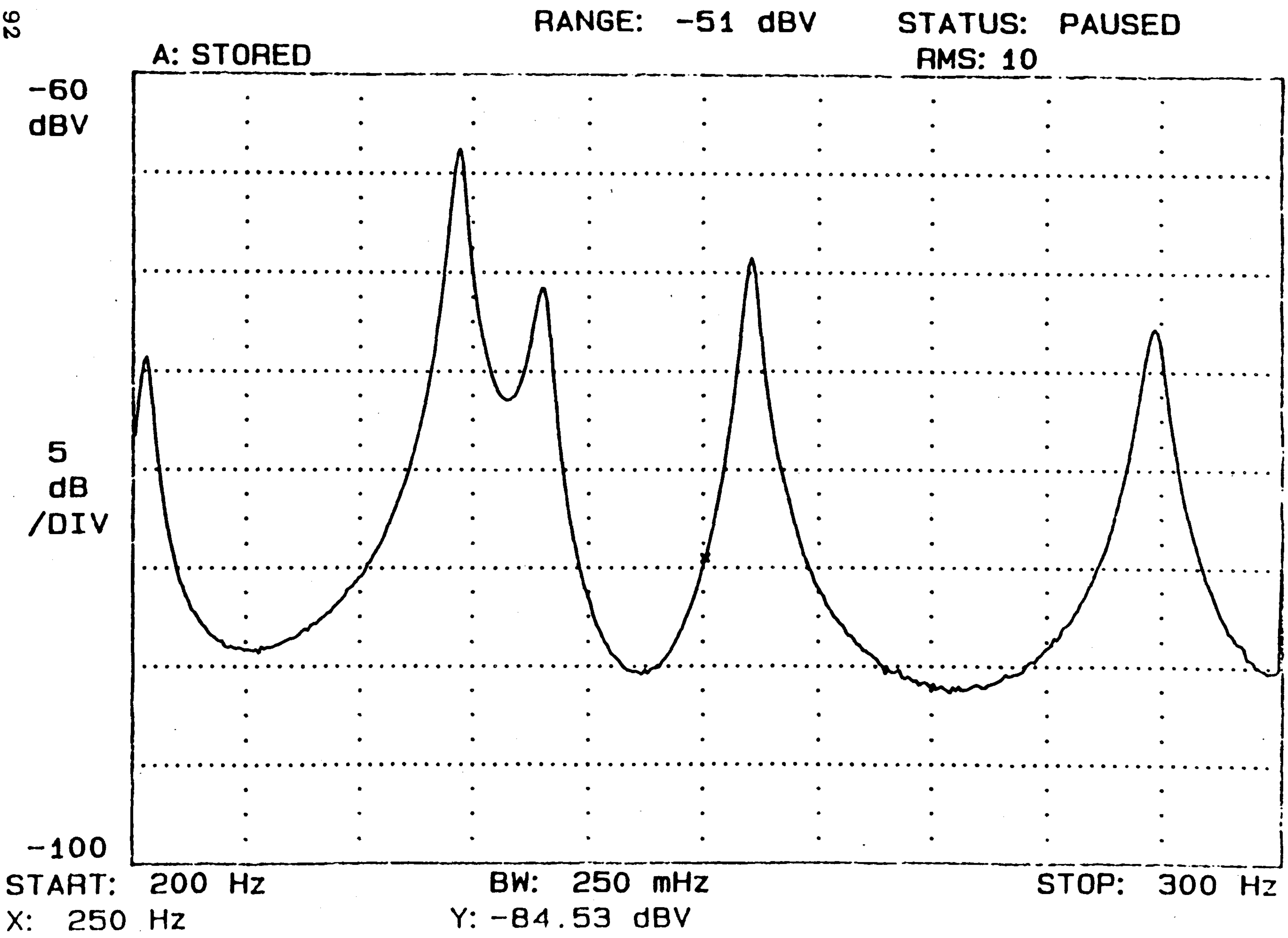

RANGE: -51 dBV
STATUS: PAUSED
A: STORED
RMS: 10
-40
dBV
10
dB
/DIV
-120
START: 0 Hz
X: 50 Hz
BW: 250 mHz
Y: -94.39 dBV
STOP: 100 Hz
25
31.5
40.0

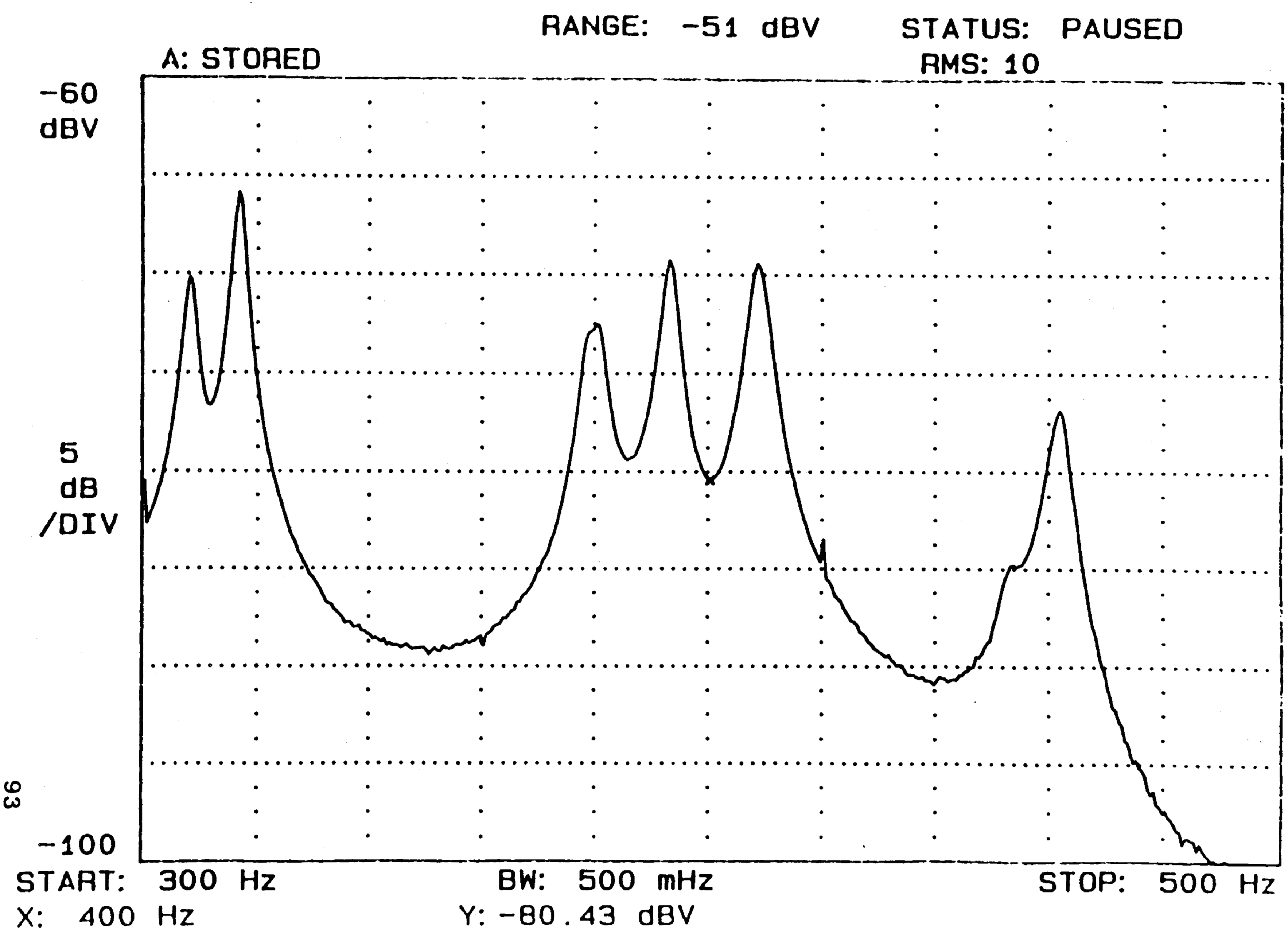
D-11341


RANGE: -51 dBV
STATUS: PAUSED
A: STORED
RMS: 10
-60
dBV
5
dB
/DIV
-100
START: 0 Hz
BW: 125 mHz
STOP: 50 Hz
X: 50 Hz
Y: -97.31 dBV

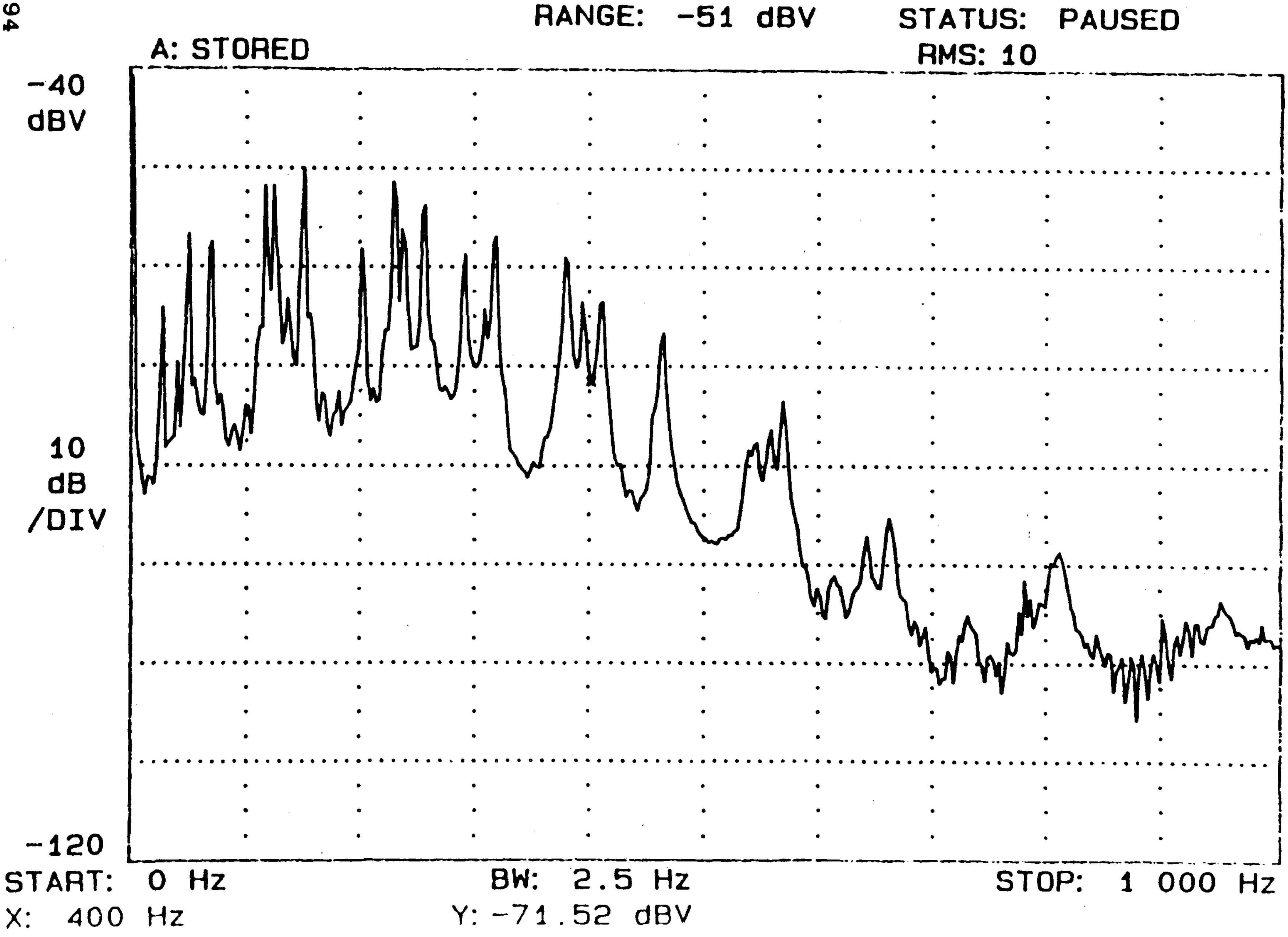

RANGE: -51 dBV
STATUS: PAUSED
A: STORED
RMS: 10
-60 dBV
5 dB /DIV
-100
START: 50 Hz
BW: 125 mHz
STOP: 100 Hz
X: 50 Hz
Y: -94.78 dBV


RANGE: -51 dBV
STATUS: PAUSED
RMS: 10
A: STORED
-60
dBV
5
dB
/DIV
-100
START: 100 Hz
BW: 250 mHz
STOP: 200 Hz
X: 150 Hz
Y: -65.63 dBV


RANGE: -51 dBV
STATUS: PAUSED
RMS: 10
A: STORED
-60
dBV
5
dB
/DIV
-100
START: 200 Hz
BW: 250 mHz
STOP: 300 Hz
X: 250 Hz
Y: -84.53 dBV

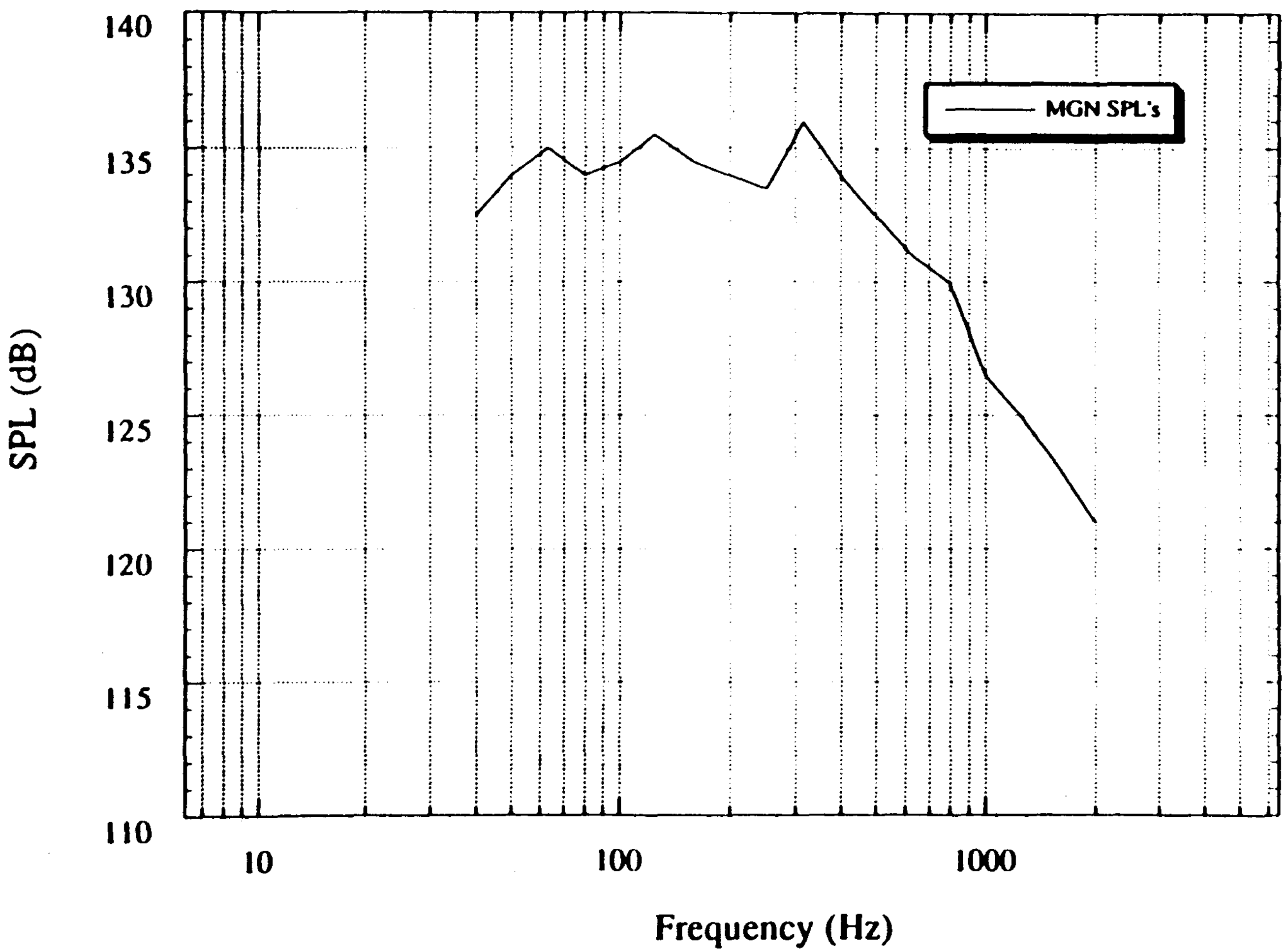


RANGE: -51 dBV
STATUS: PAUSED
RMS: 10
A: STORED
-60
dBV
5
dB
/DIV
-100
START: 300 Hz
BW: 500 mHz
STOP: 500 Hz
X: 400 Hz
Y: -80.43 dBV


RANGE: -51 dBV
STATUS: PAUSED
RMS: 10
A: STORED
-40
dBV
10
dB
/DIV
-120
START: 0 Hz
BW: 2.5 Hz
STOP: 1 000 Hz
X: 400 Hz
Y: -71.52 dBV

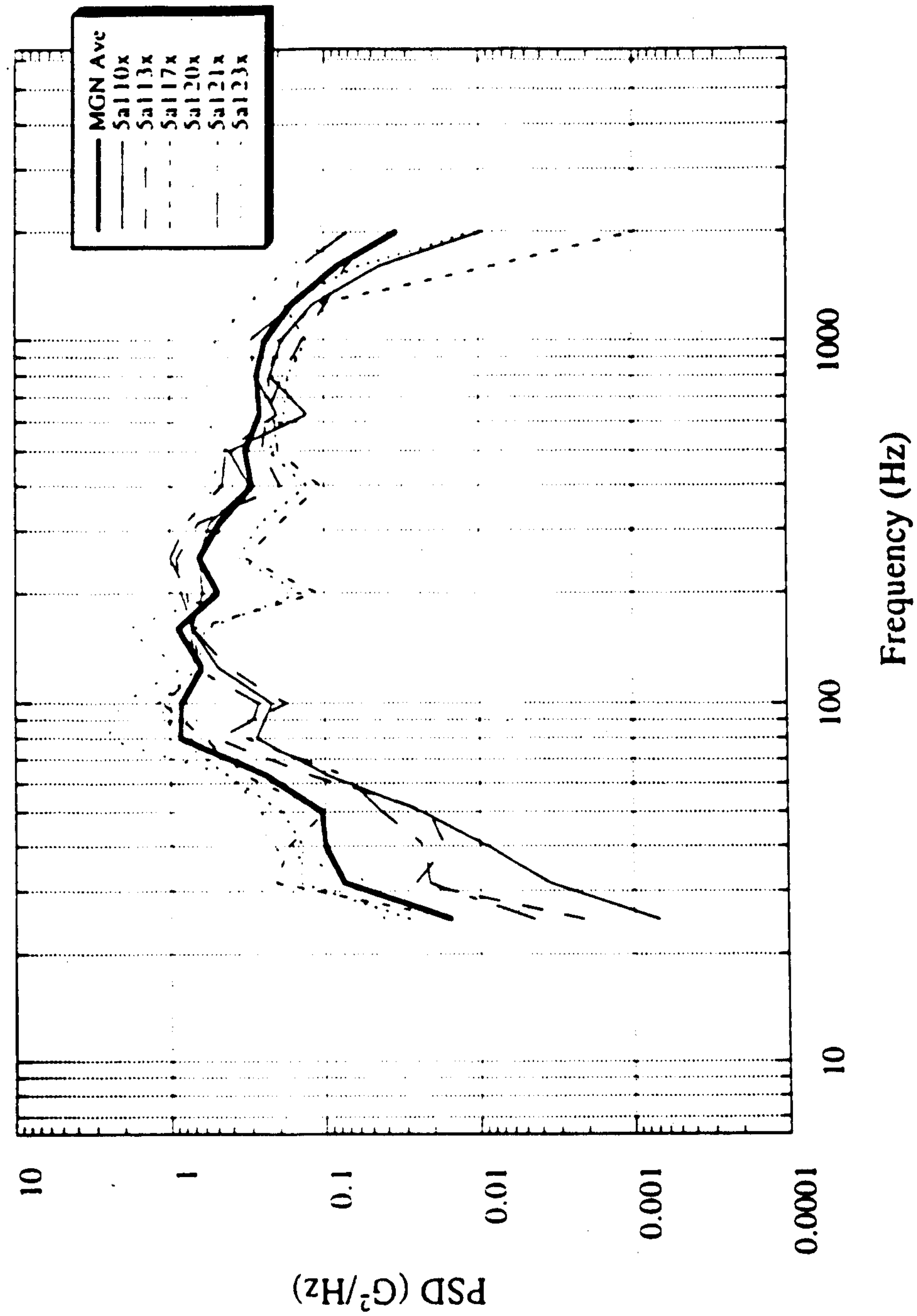
Appendix C:

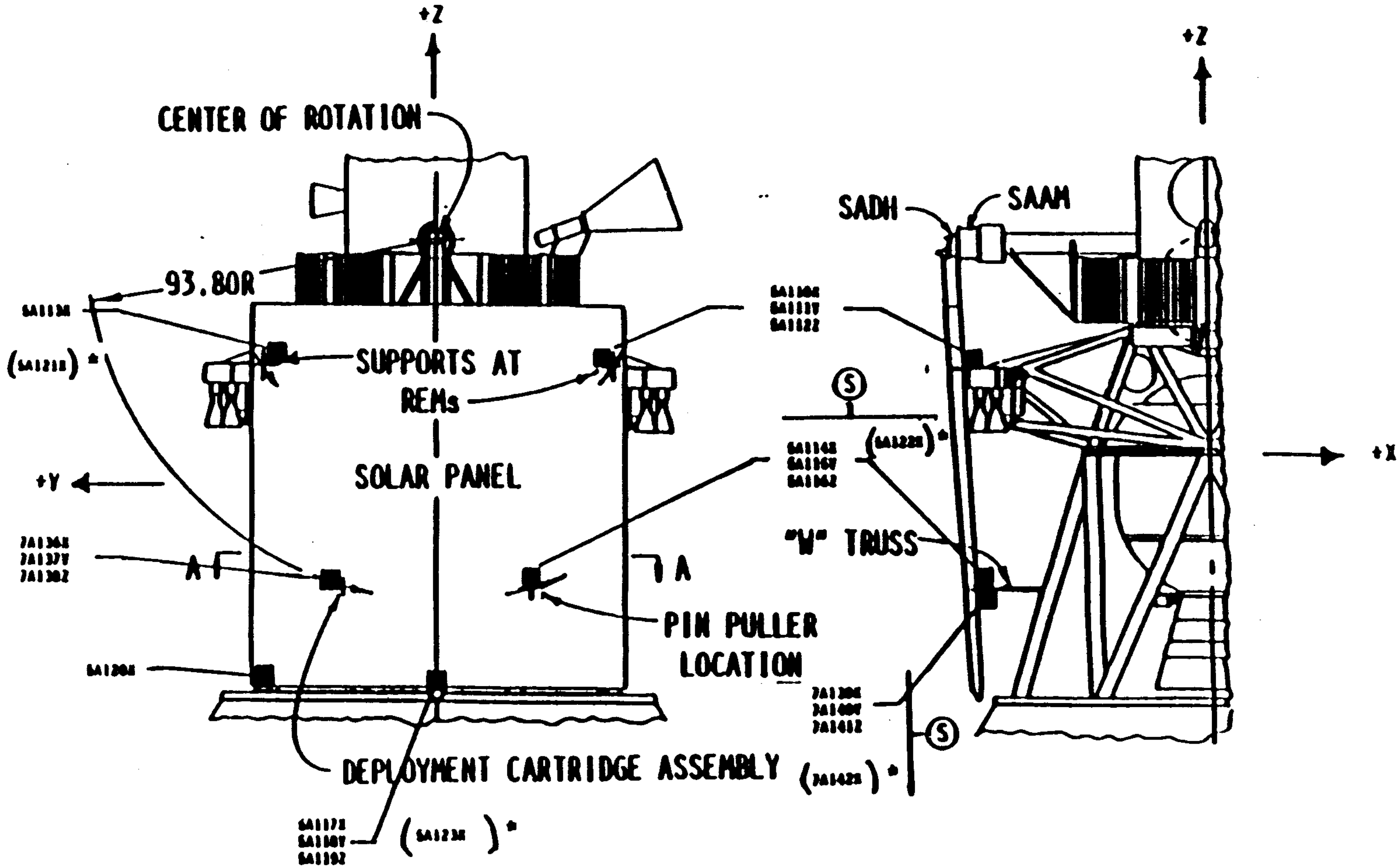
Magellan Solar Panels (DMM)
Data from S/C System Acoustic Test



Magellan S/C System Acoustic Test SPL's for DMM Solar Panel

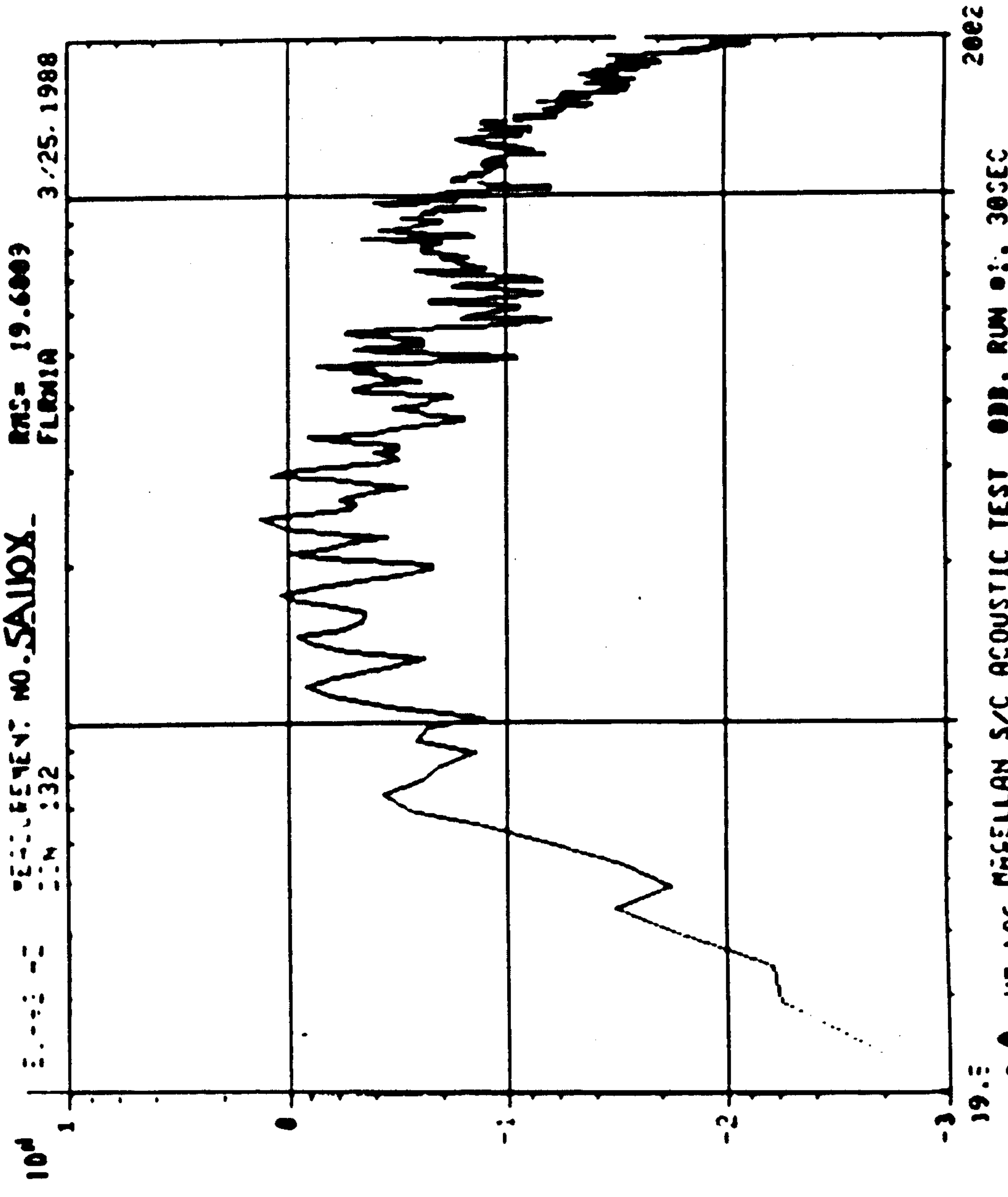
Magellan S/C System Acoustic Test Data for DMM Solar Panel 1/3-Octave Band Data

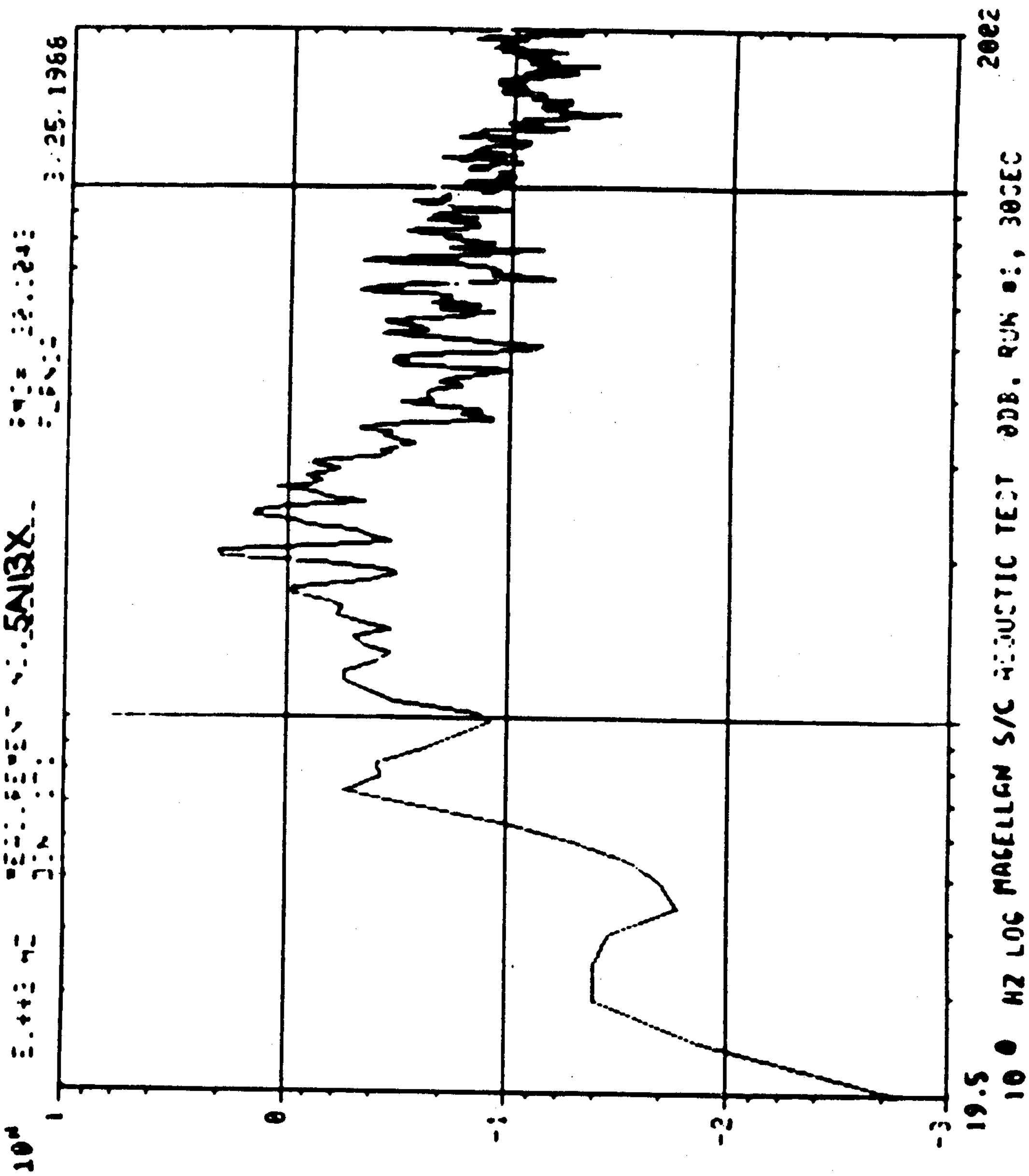


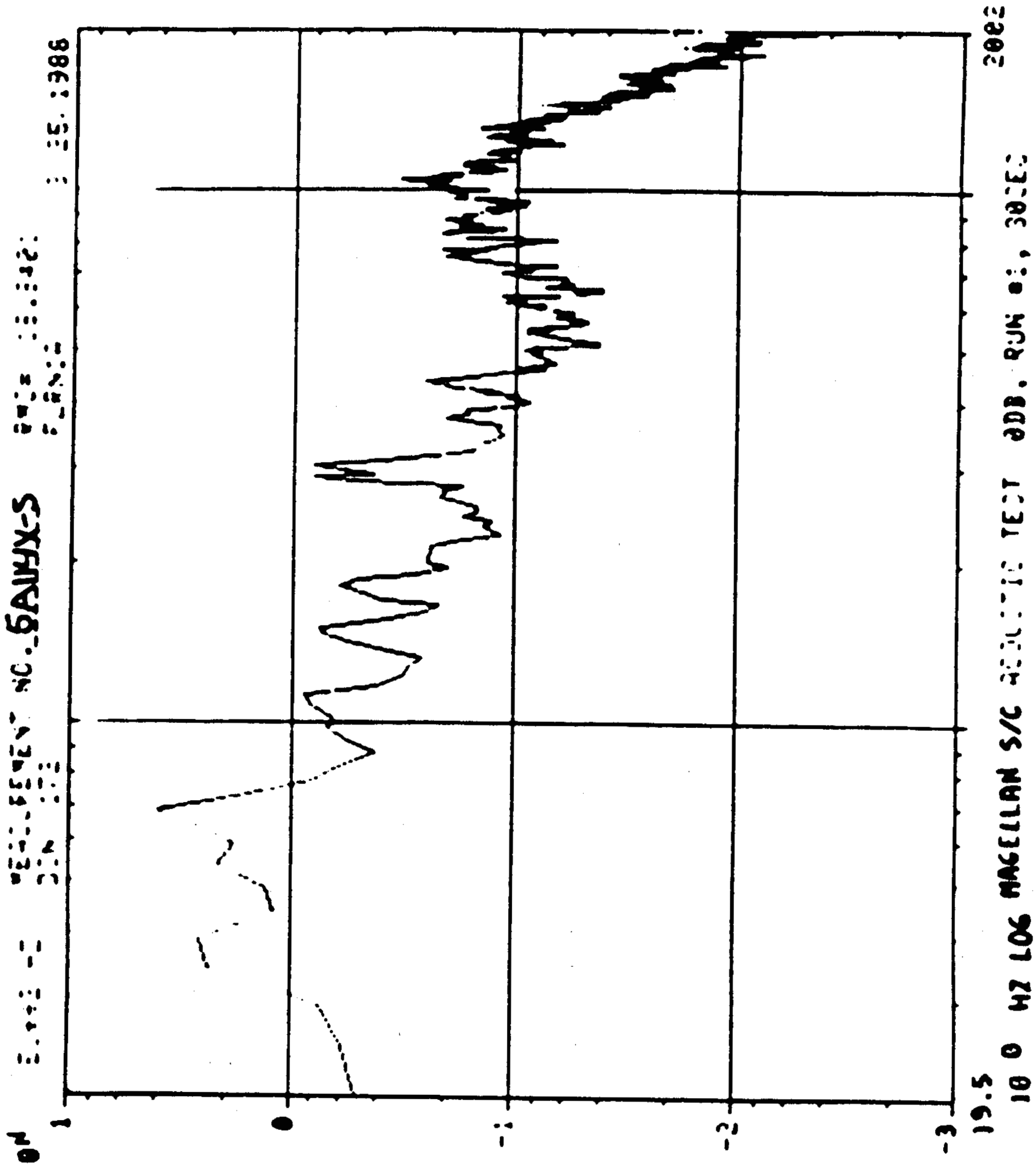


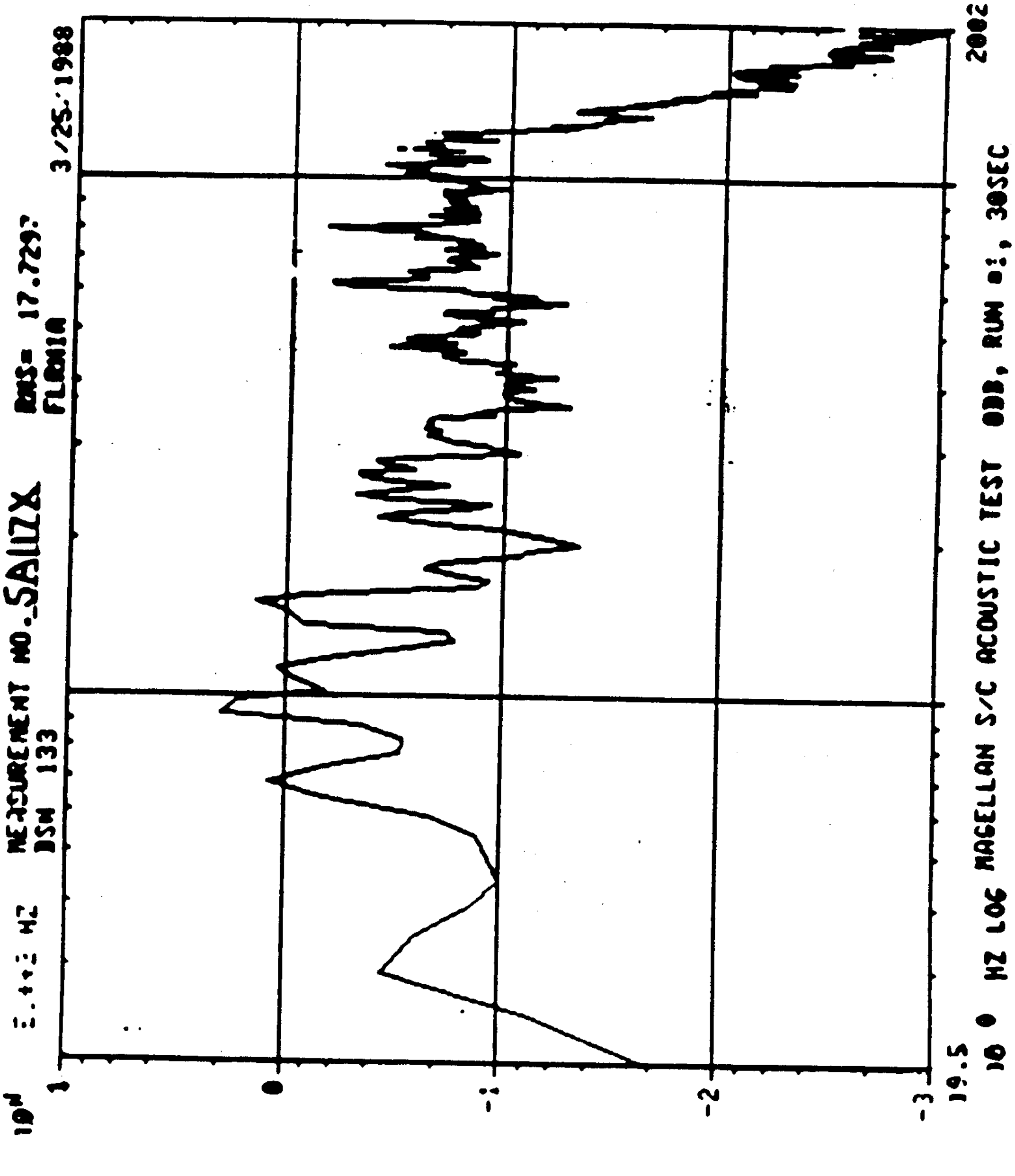
* Measurement on +X Array

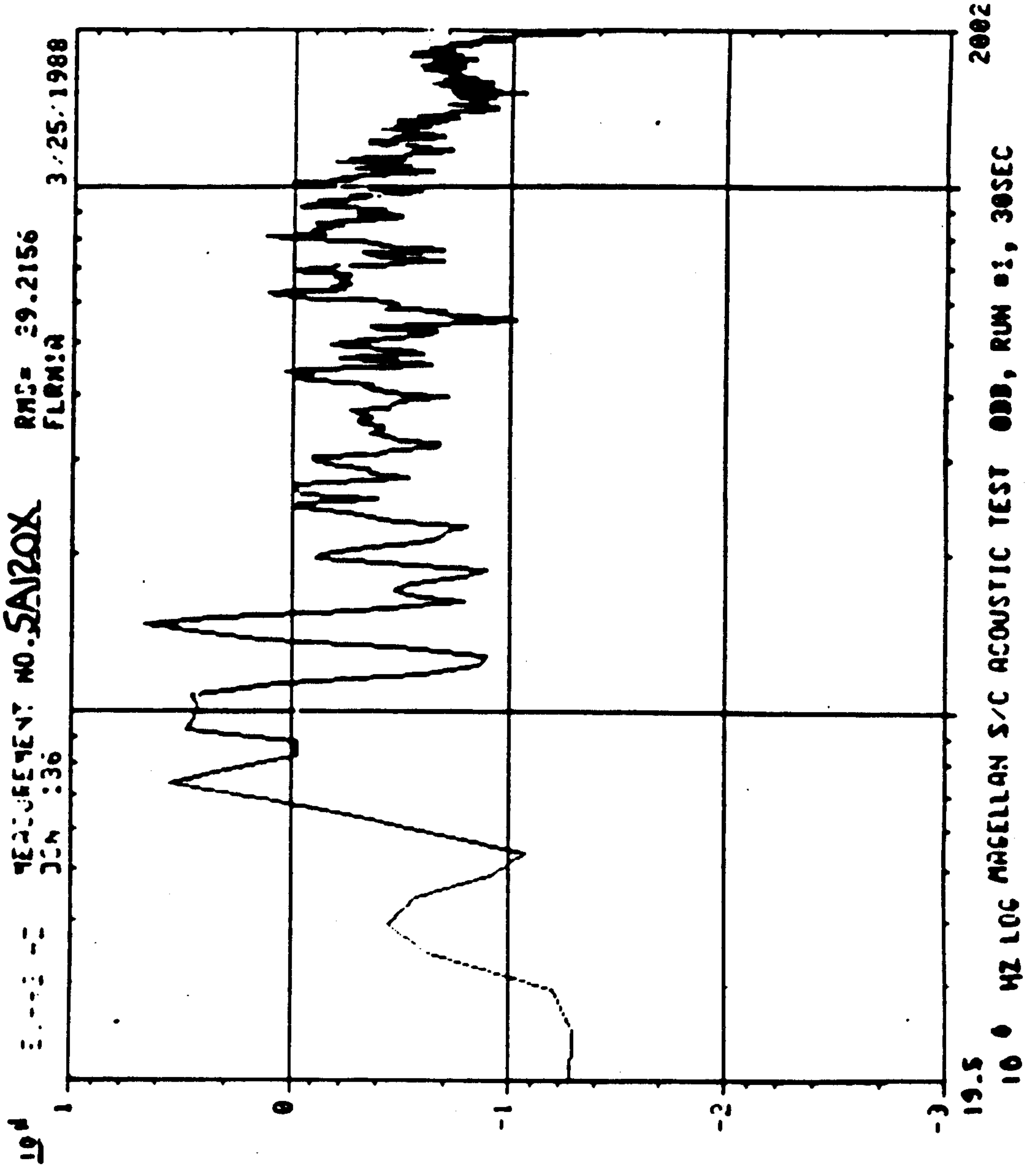
Magellan Spacecraft Solar Panels - Accelerometer Locations

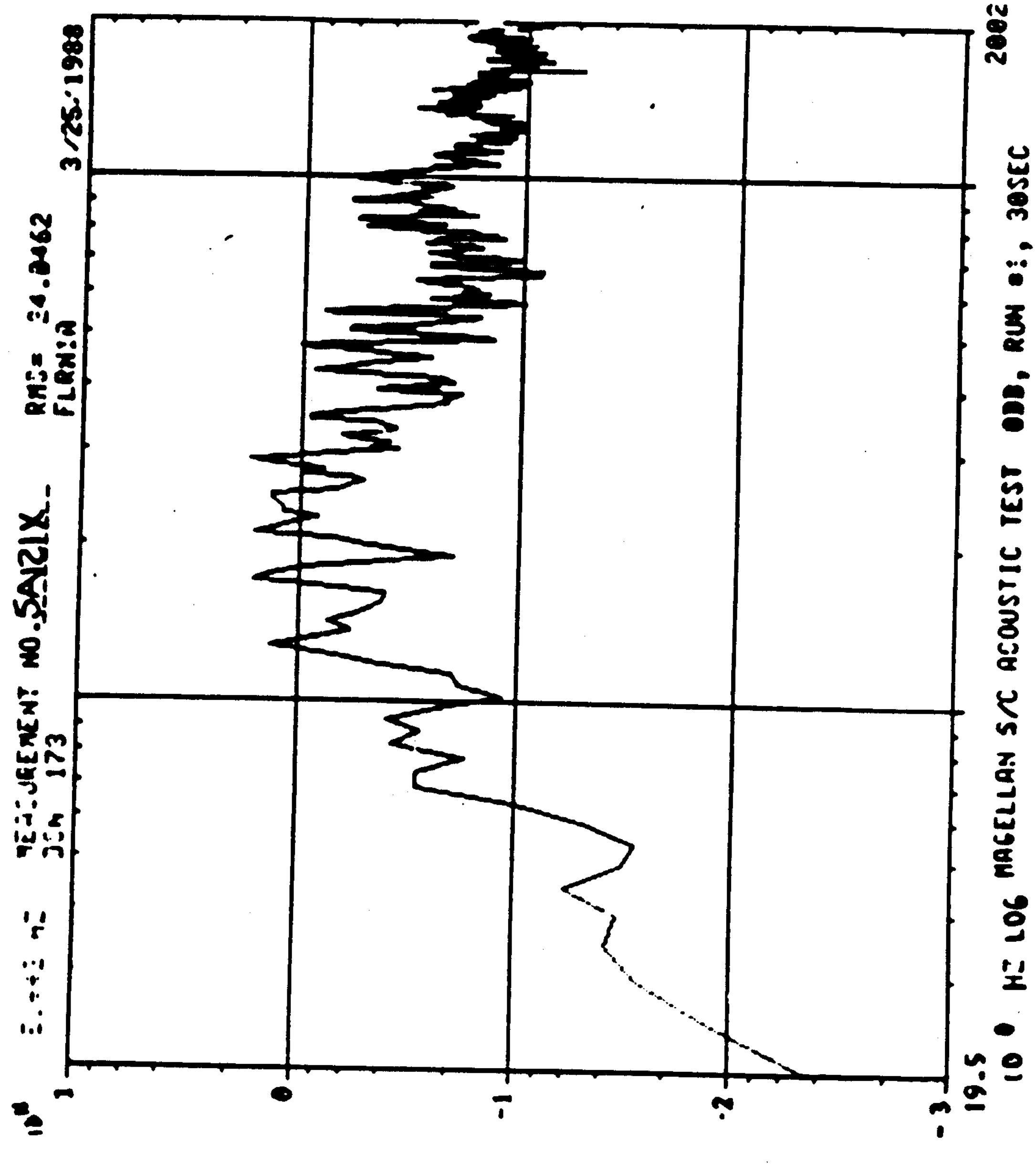

3/25.1988
RMS= 19.6003
HZ LOG MAGELLAN S/C ACOUSTIC TEST 0DB, RUN #1, 30SEC
19.5
2002
1
0
-1
-2
-3


5A13X
HZ LOG MAGELLAN S/C
19.5
2002
10
0
-1
-2
-3

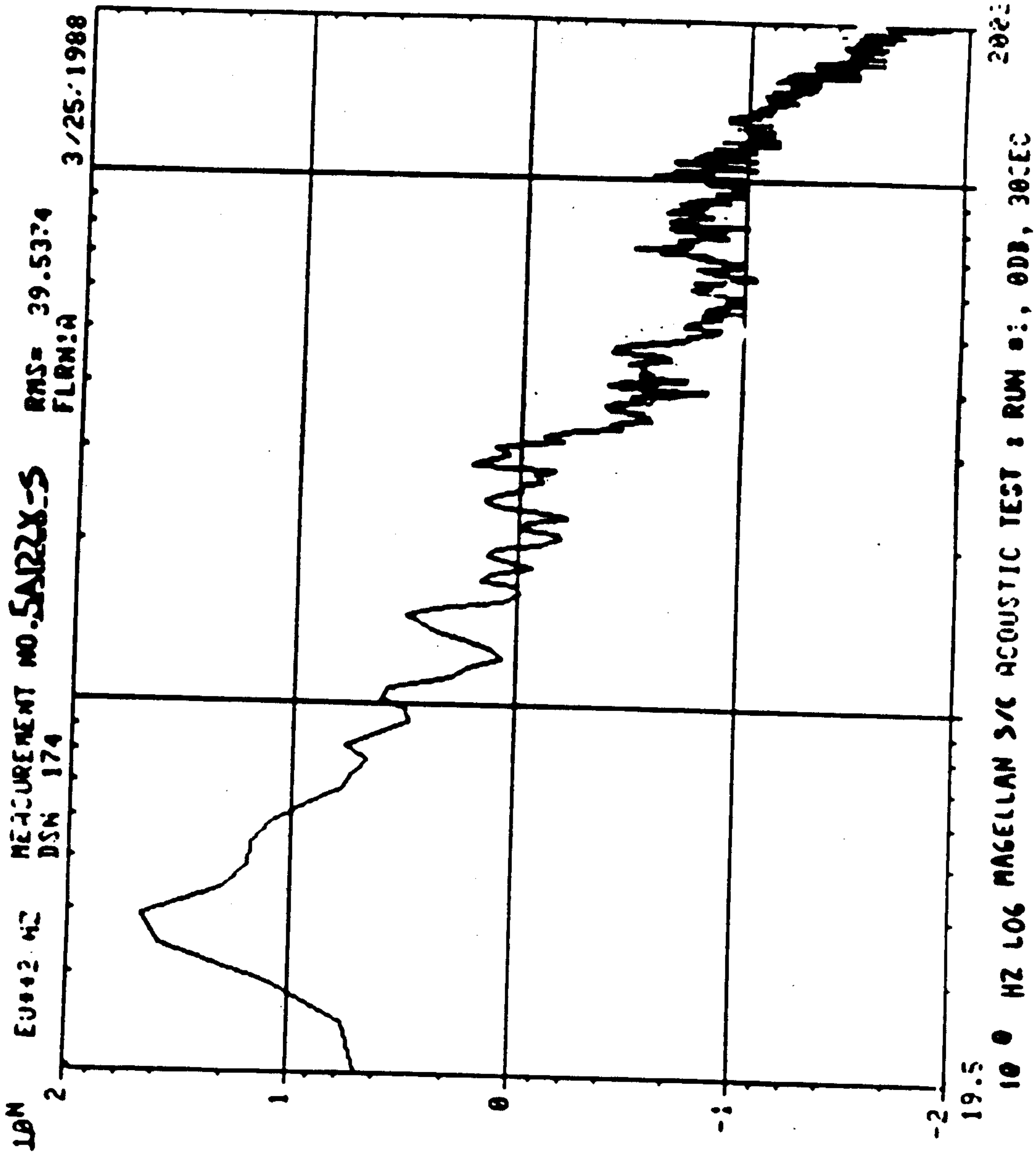

6AIMX-S
10 0 HZ LOG MAGELLAN S/C
TEST 0DB. RUN
19.5
2002
10N
1
0
-1
-2
-3


MEASUREMENT NO. SA117X
RMS= 17.7297
3/25/1988
HZ LOG MAGELLAN S/C ACOUSTIC TEST 0DB, RUN #1, 30SEC
19.5
2002
1
0
-1
-2
-3

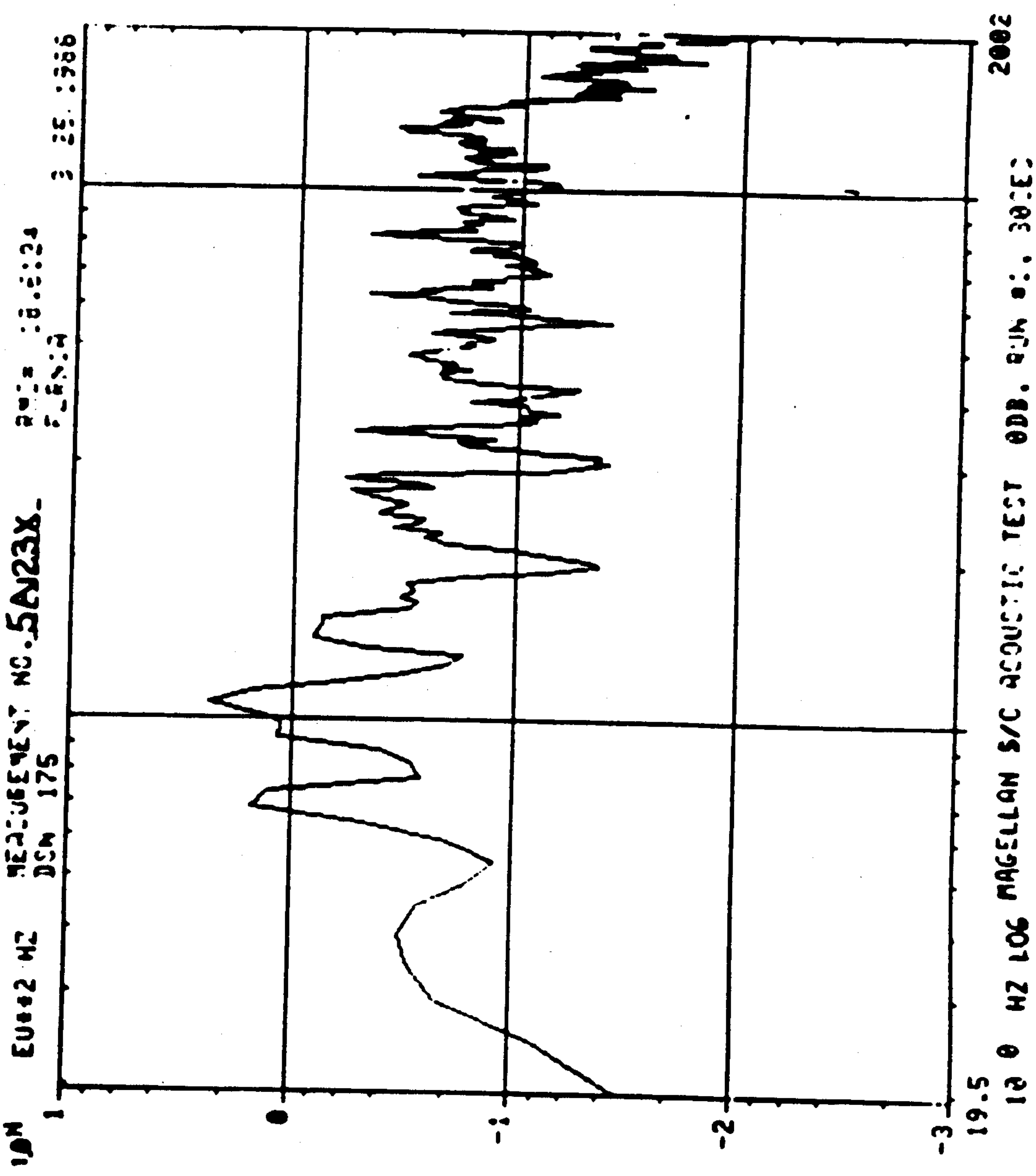

MEASUREMENT NO. SA120X
RMS= 29.2156
3/25/1988
HZ LOG MAGELLAN S/C ACOUSTIC TEST
RUN #1, 30SEC
19.5
2002
1
0
-1
-2
-3



MEASUREMENT NO. 5A121X
RMS= 24.0462
3/25/1988
10 0 HZ LOG MAGELLAN S/C ACOUSTIC TEST 0DB, RUN #1, 30SEC
2002
19.5
1
0
-1
-2
-3

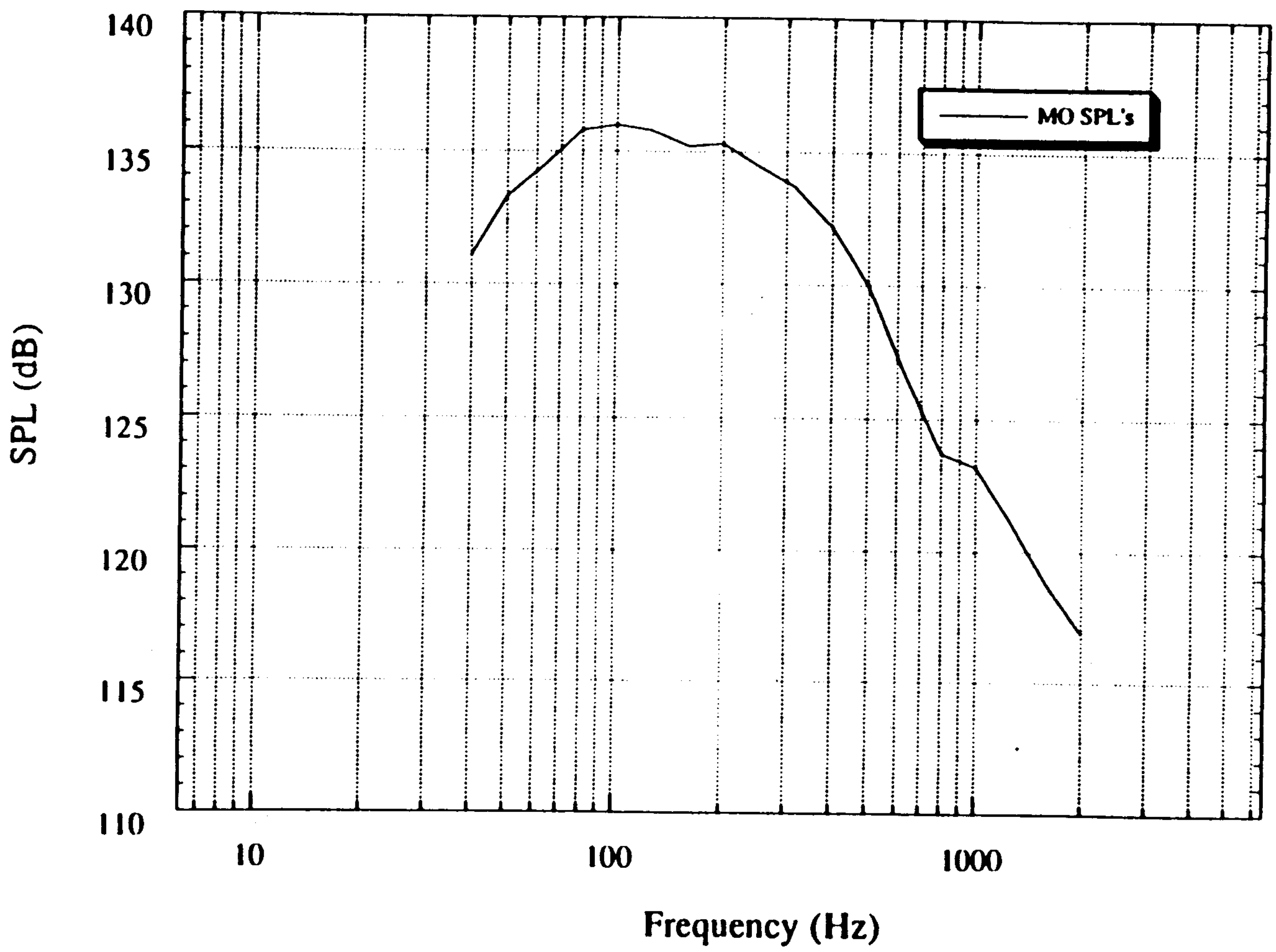


10^N
EU##2 HZ
MEASUREMENT NO. 5A122X-5
DSN 174
RMS= 39.5374
FLRN:A
3/25/1988
2
1
0
-1
-2
19.5
2023
10 ● HZ LOG MAGELLAN S/C ACOUSTIC TEST : RUN #1, 0DB, 30SEC


MEASUREMENT NO. 5AJ23X
DSN 175
HZ LOG MAGELLAN S/C ACOUSTIC TEST
19.5
2002
1
0
-1
-2
-3

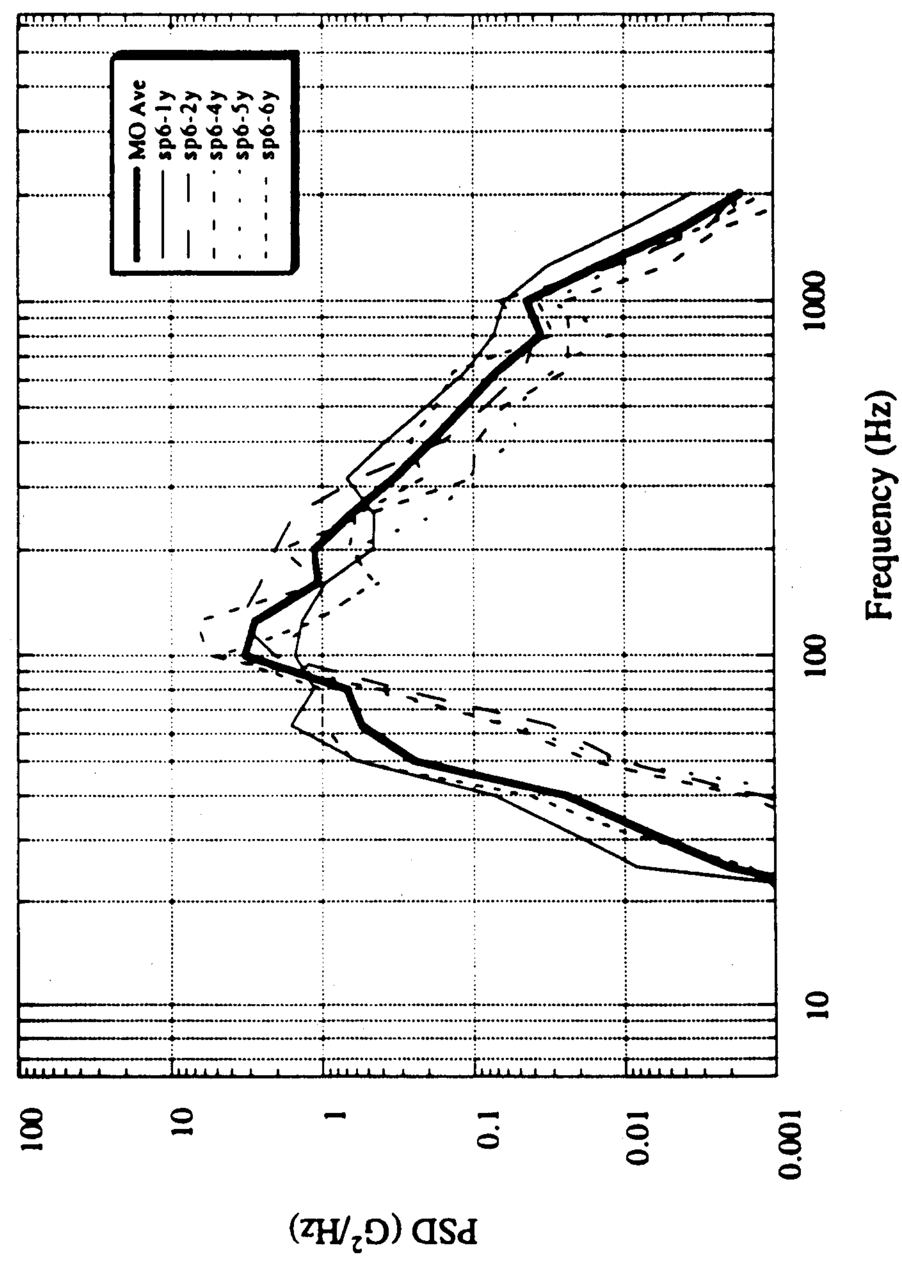
Appendix D:

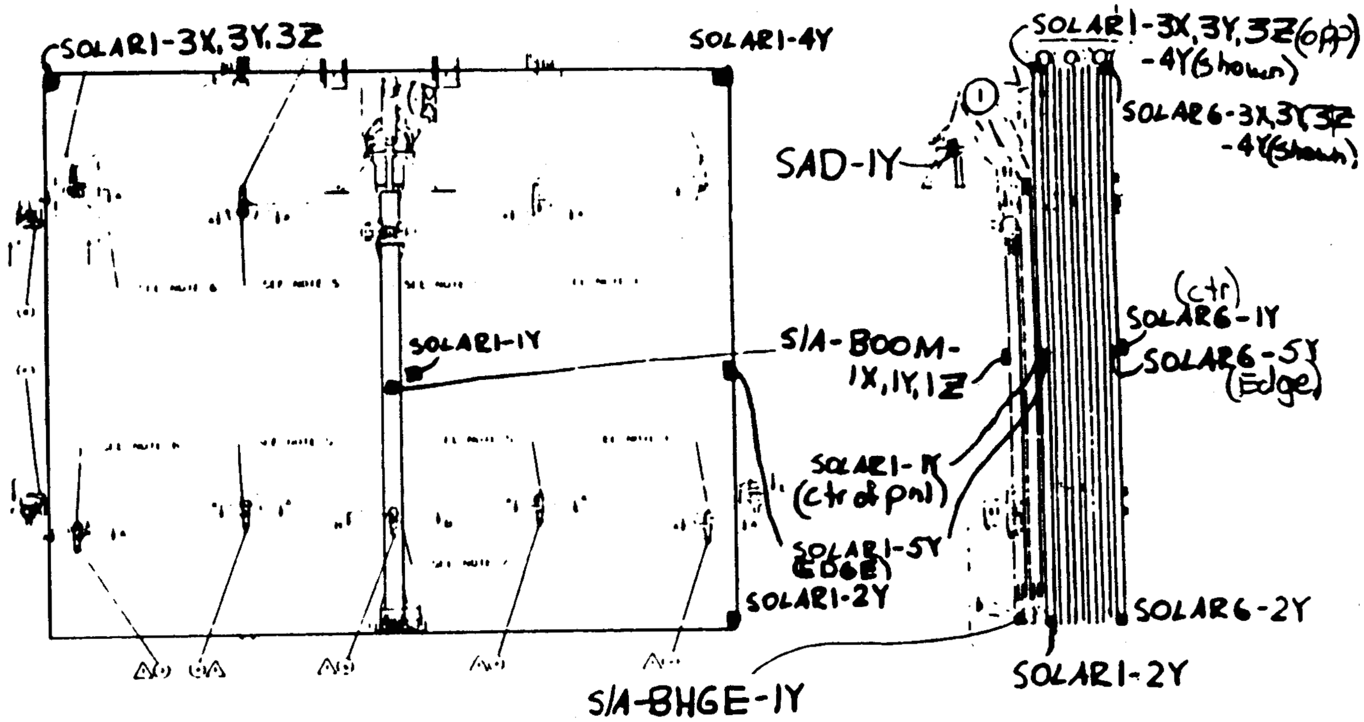
Mars Observer Solar Panels
Data from S/C System Acoustic Test



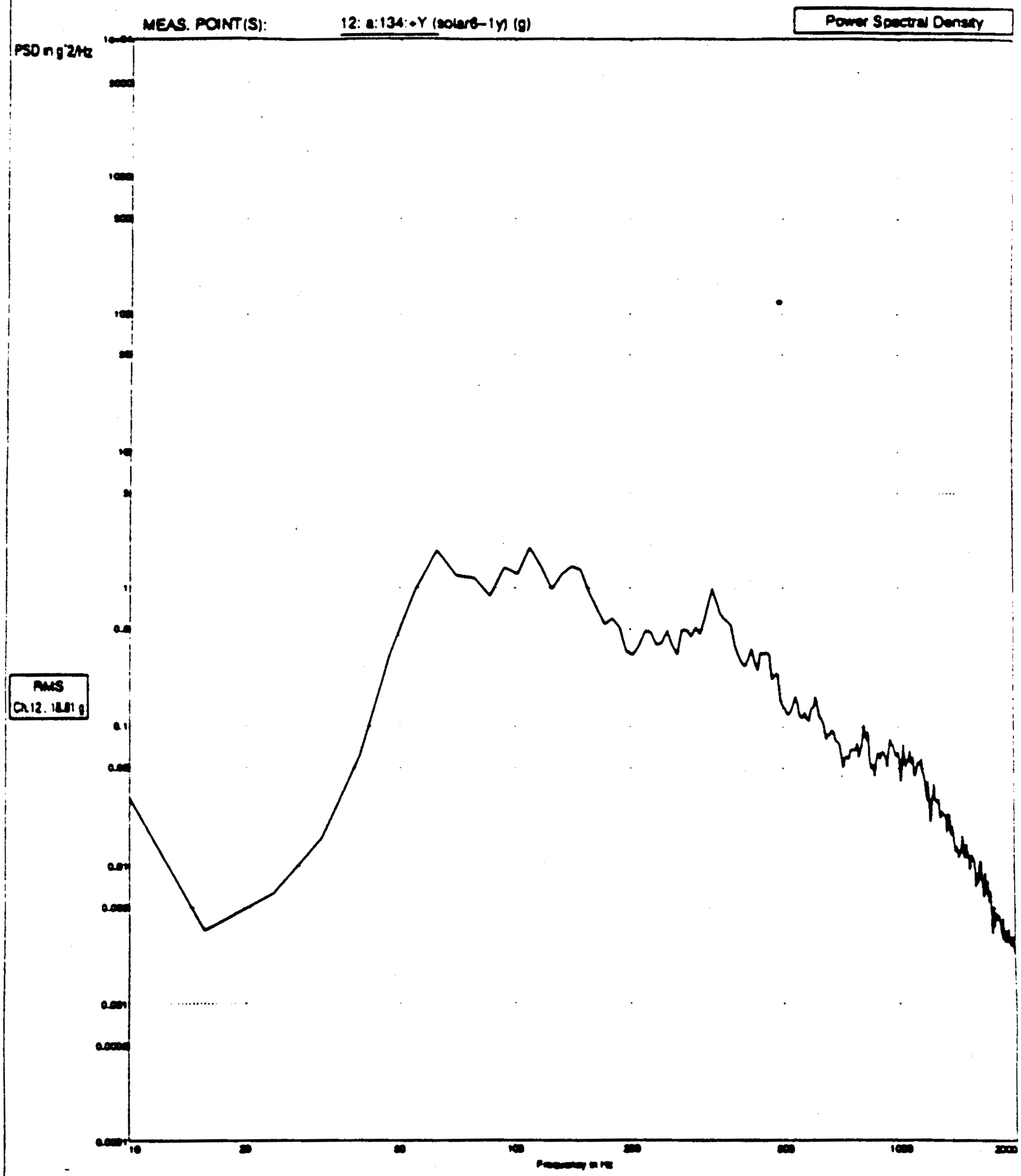
Mars Observer S/C System Acoustic Test SPL's

Mars Observer System Acoustic Test Data for Solar Panel 6
1/3-Octave Band Data



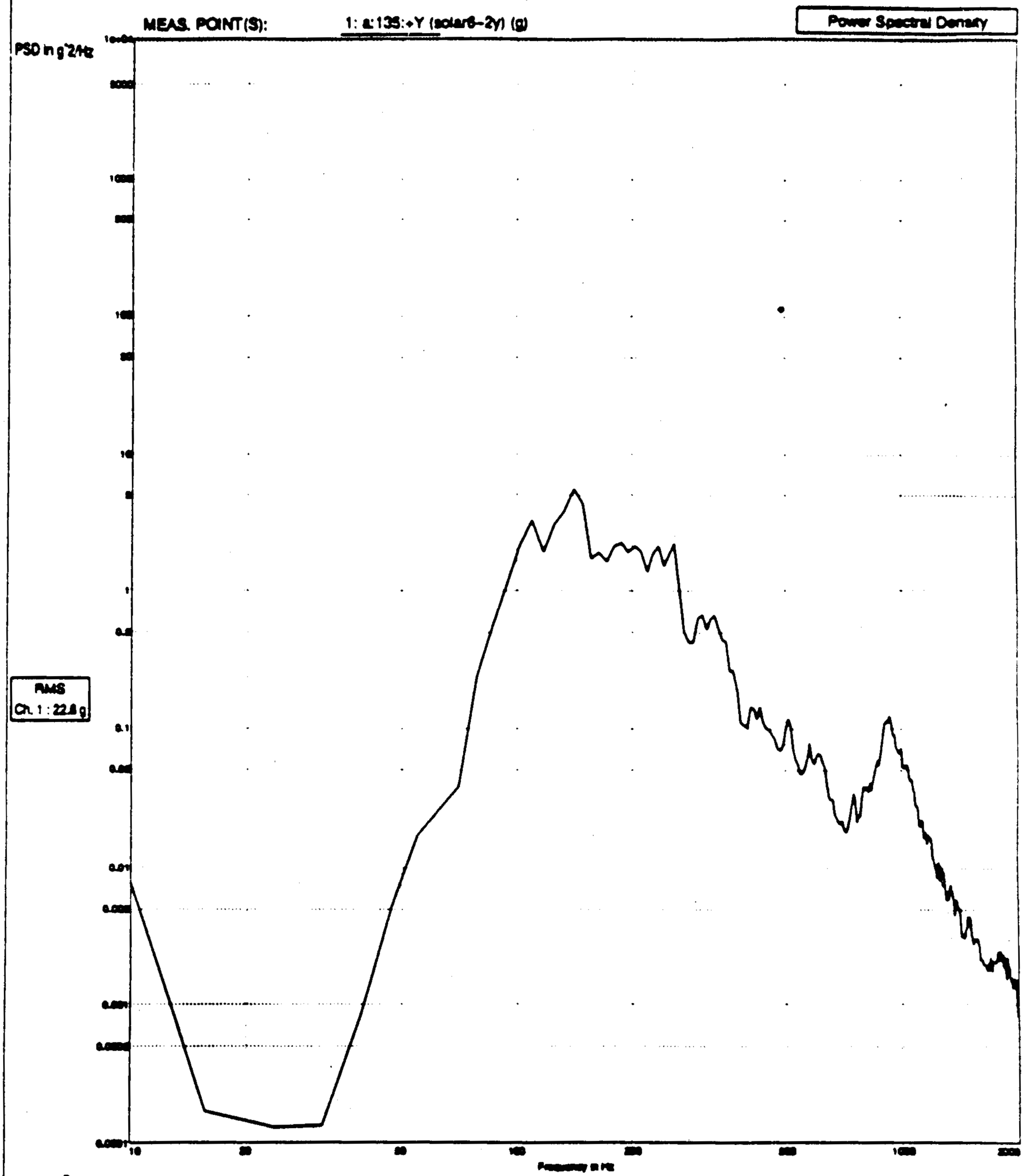


Mars Observer Spacecraft Solar Panels - Accelerometer Locations



PROJECT : mars observer	AXIS : 145.8		
ITEM(S/N) : space craft	TEST TYPE : proto level	E.T.R.: 5936	
MODE : Random (nDOF= 187)(df:7.812)	REF. POINT :	SEQ. : 109 (4-17-92)	

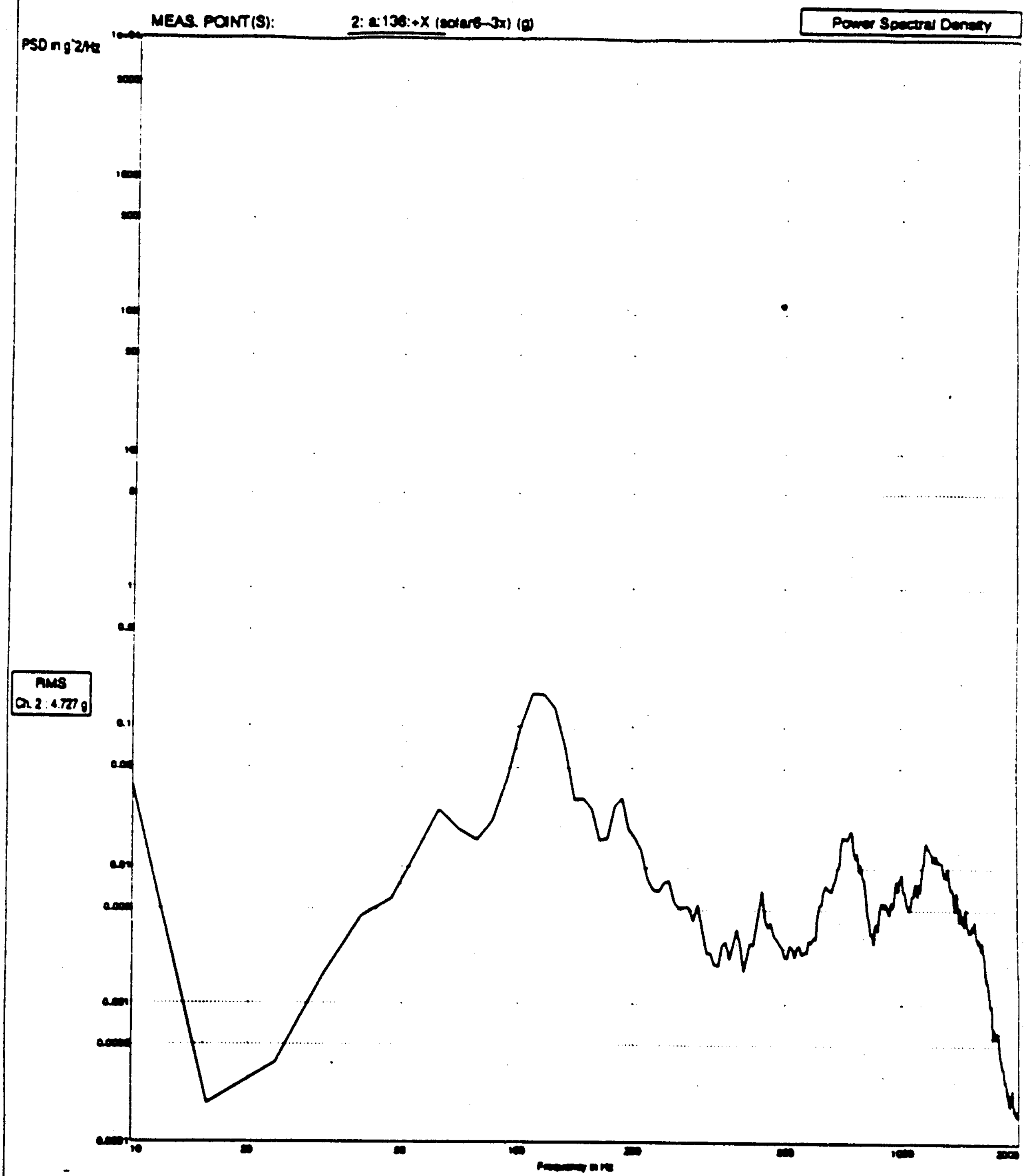
GE ASTRO SPACE



GE ASTRO SPACE

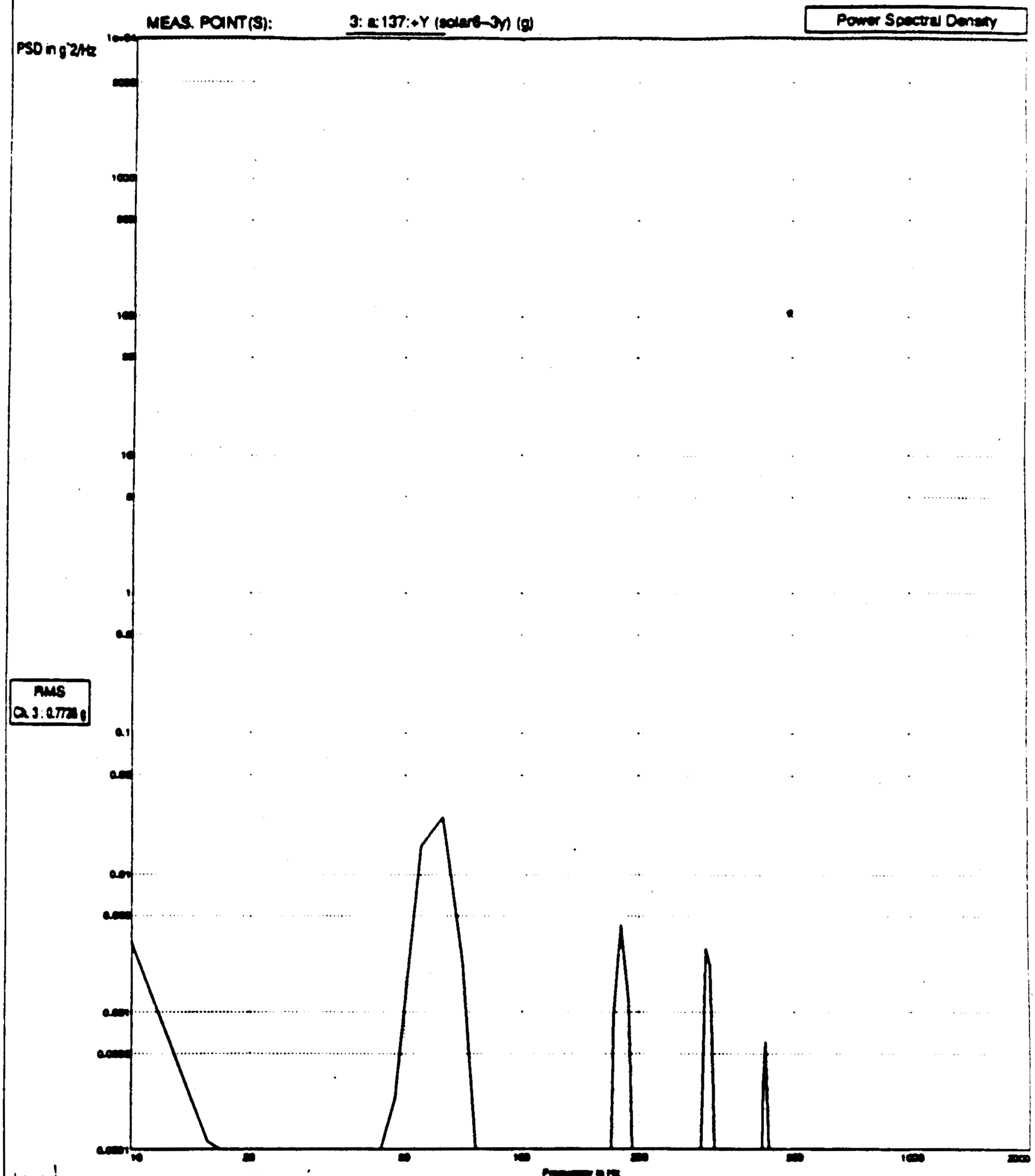
PROJECT	: mars observer	AXIS	: 145.8		
ITEM(S/N)	: space craft	TEST TYPE	: proto level	E.T.R.:	5936
MODE	: Random (nDOF= 187)(df:7.812)	REF. POINT	:	SEQ.	: 111 (4-17-92)

SYMMEX VAP 2000/Analysis



PROJECT : mars observer	AXIS : 145.8	GE ASTRO SPACE
ITEM(S/N) : space craft	TEST TYPE : proto level	E.T.R.: 5936
MODE : Random (nDOF= 187)(df:7.812)	REF. POINT :	SEQ. : 111 (4-17-92)

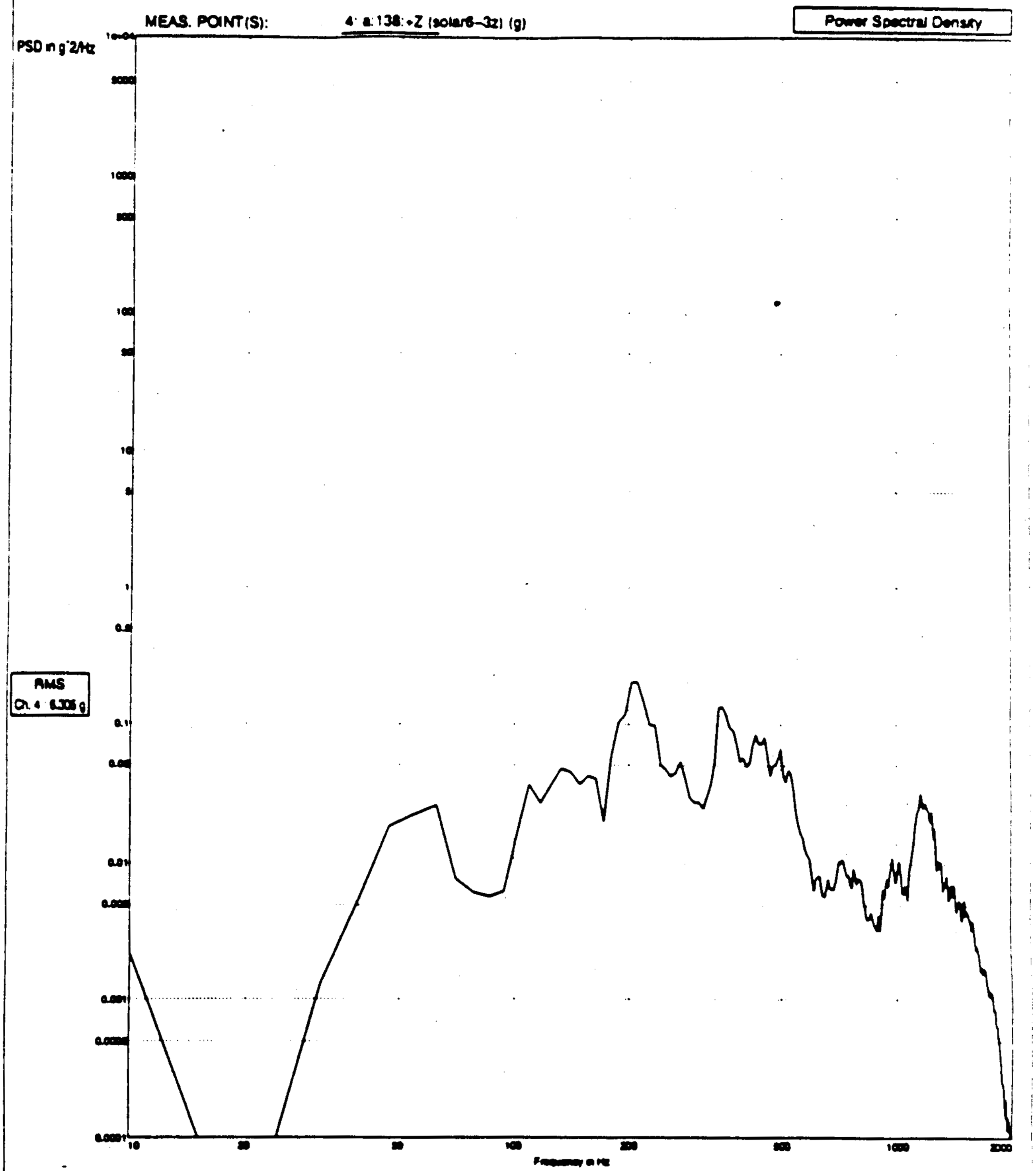
SYMNEX VAP 2000/Analysis



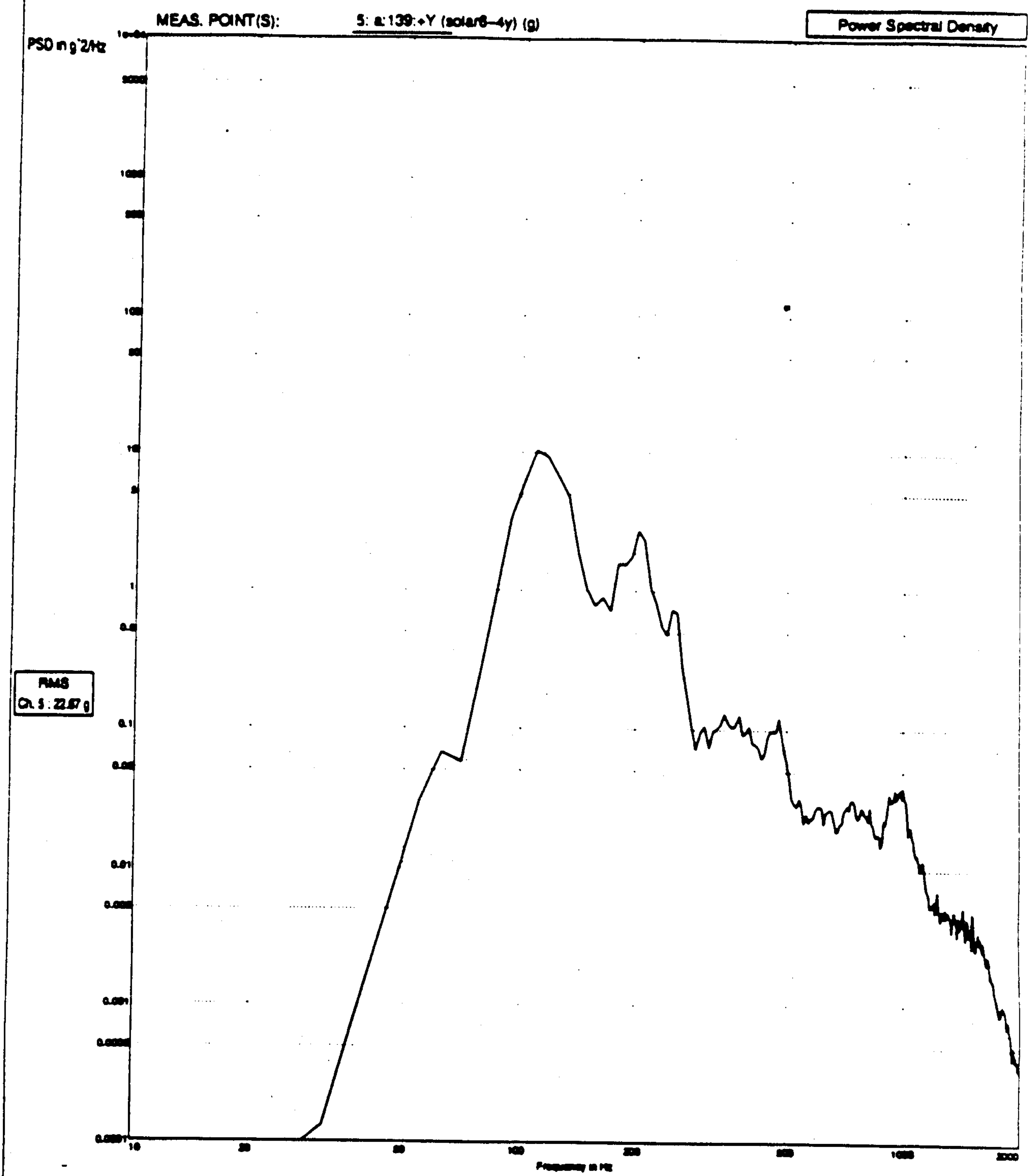
* Note. Bad Data (not used)

GE ASTRO SPACE

PROJECT	: mars observer	AXIS	: 145.8		
ITEM(S/N)	: space craft	TEST TYPE	: proto level	E.T.R.:	5936
MODE	: Random (nDOF= 187)(df:7.812)	REF. POINT	:	SEQ. :	111 (4-17-92)



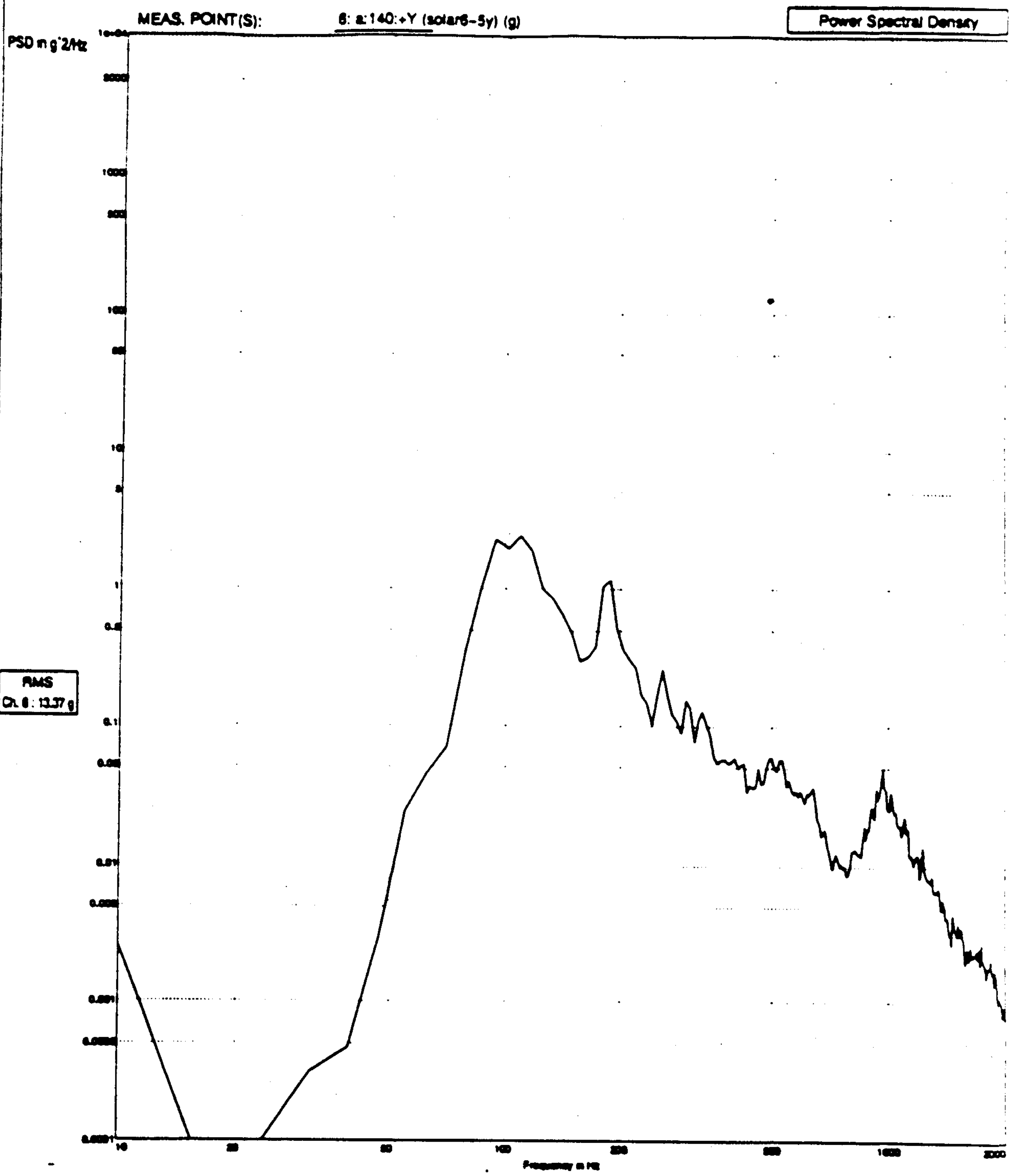
PROJECT : mars observer	AXIS : 145.8	GE ASTRO SPACE
ITEM(S/N) : space craft	TEST TYPE : proto level	E.T.R.: 5936
MODE : Random (nDOF= 187)(df:7.812)	REF. POINT :	SEQ. : 111 (4-17-92)



PROJECT : mars observer
ITEM(S/N) : space craft
MODE : Random (nDOF= 187)(df:7.812)

AXIS : 145.8
TEST TYPE : proto level
REF. POINT :

GE ASTRO SPACE
E.T.R.: 5936
SEQ. : 111 (4-17-92)

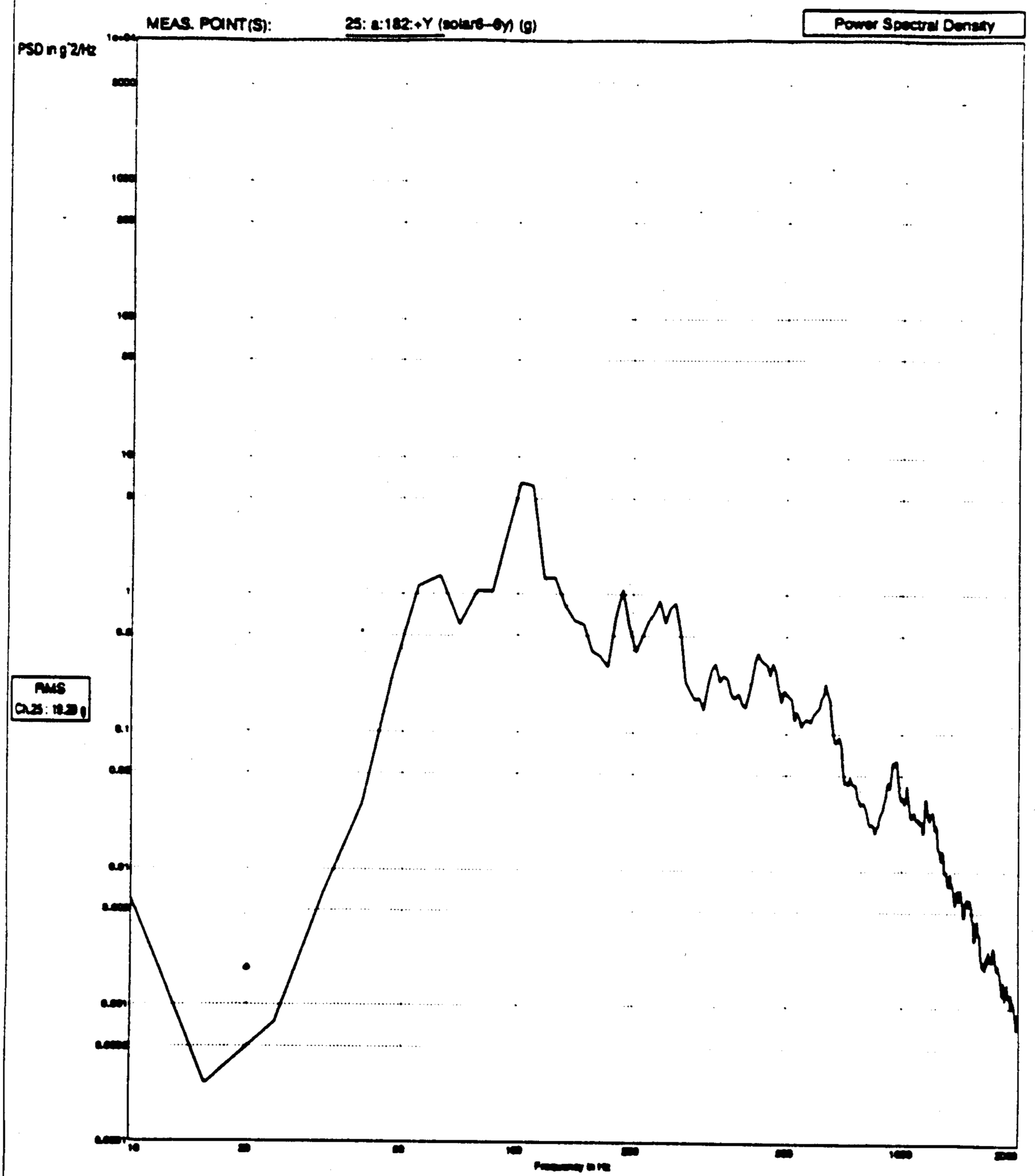


GE ASTRO SPACE

PROJECT : mars observer
ITEM(S/N) : space craft
MODE : Random (nDOF= 187)(df:7.812)

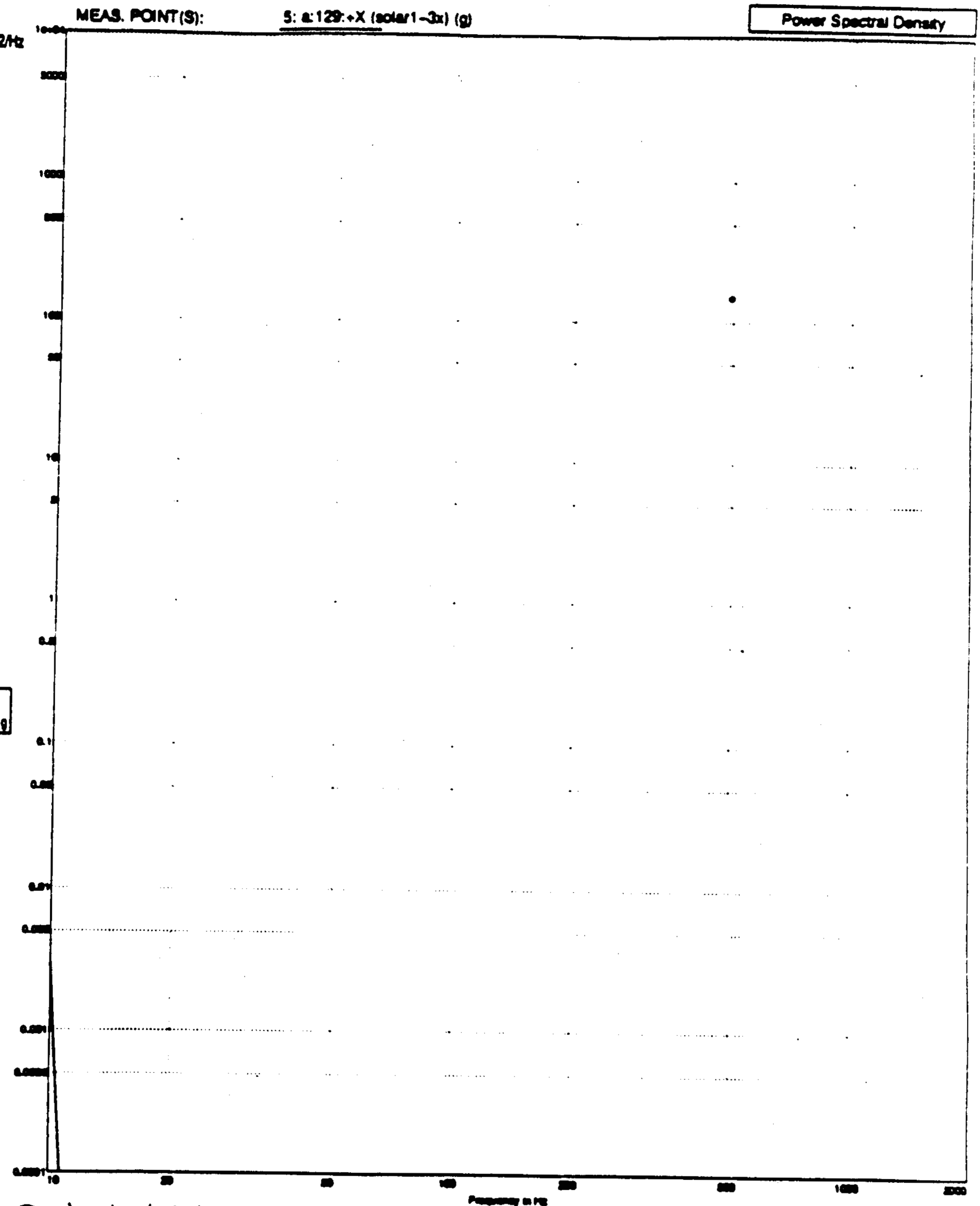
AXIS : 145.8
TEST TYPE : proto level
REF. POINT :

E.T.R.: 5936
SEQ. : 111 (4-17-92)



PROJECT : MARS OBSERVER	AXIS : 145.8	**GE ASTRO SPACE**
ITEM(S/N) : S/C 001	TEST TYPE : proto level	E.T.R.: 5936
MODE : Random (nDOF= 187)(df:7.812)	REF. POINT :	SEQ. : 116 (4-17-92)

SYNAMEX VAP 2000/Analysis

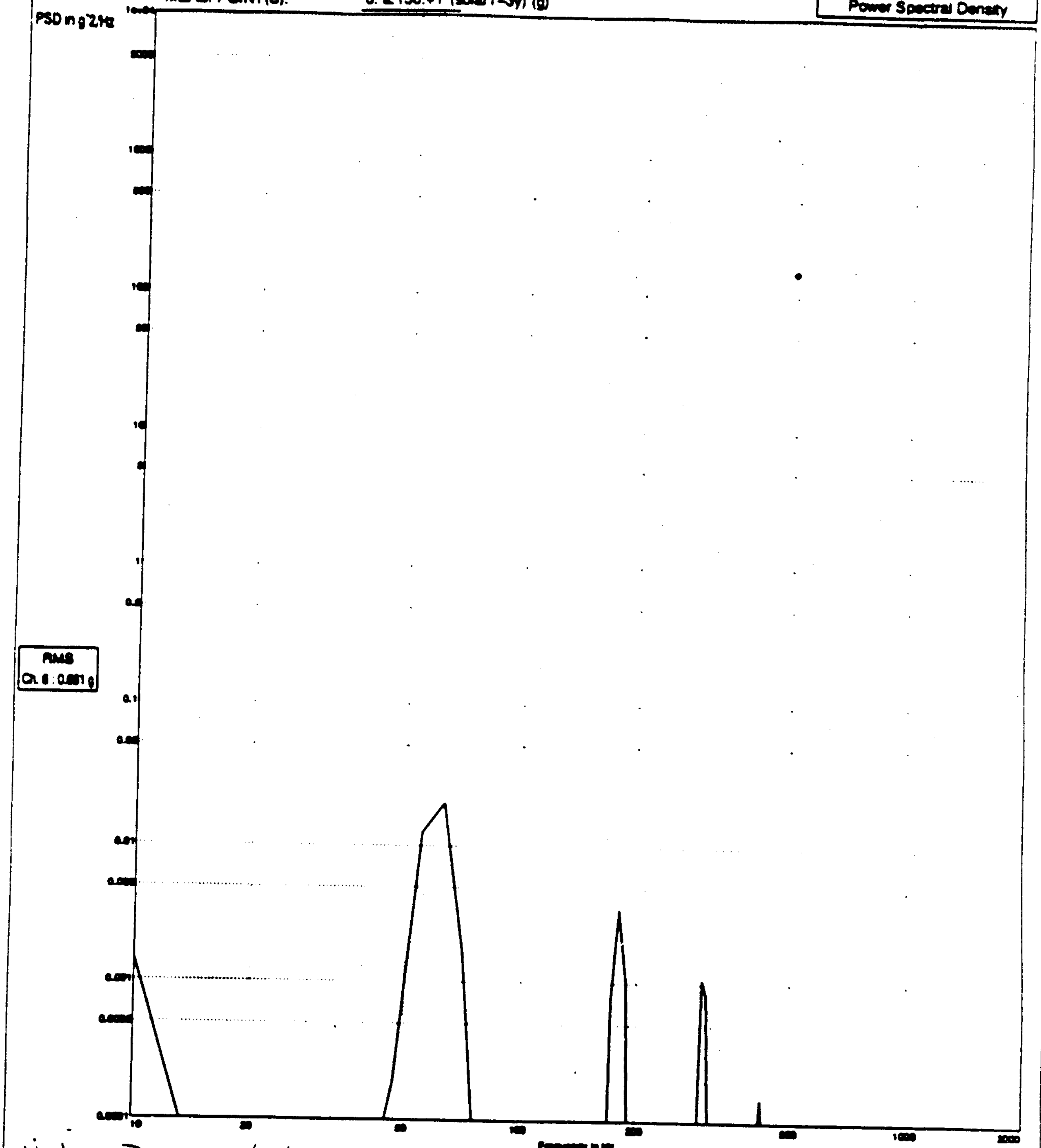


Note: Bad Data (Not used)

PROJECT	: mars observer	AXIS	: 145.8	**GE ASTRO SPACE**	
ITEM(S/N)	: space craft	TEST TYPE	: proto level	E.T.R.: 5936	
MODE	: Random (nDOF= 187)(df:7.812)	REF. POINT	:	SEQ. : 107 (4-16-92)	

MEAS. POINT(S): 6: a:130:+Y (solar1-3y) (g)

Power Spectral Density



Note. F=1?Hz (actual)

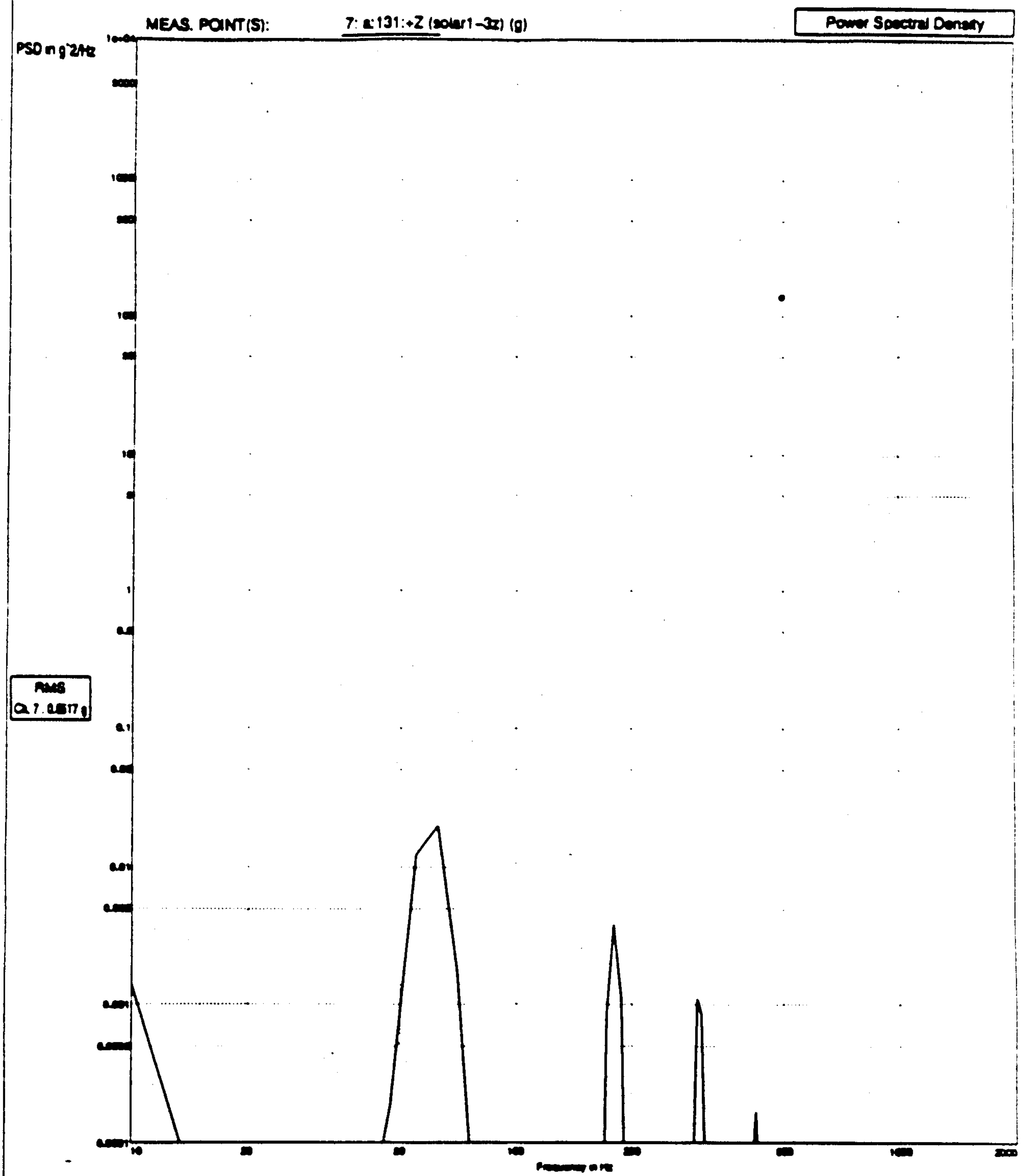
PROJECT : mars observer
ITEM(S/N) : space craft
MODE : Random (nDOF= 187)(df:7.812)

AXIS : 145.8
TEST TYPE : proto level
REF. POINT :

GE ASTRO SPACE

E.T.R.: 5936
SEQ. : 107 (4-16-92)

SYMMEX VAP 2000/Analysis



PROJECT : mars observer	AXIS : 145.8	GE ASTRO SPACE
ITEM(S/N) : space craft	TEST TYPE : proto level	E.T.R.: 5936
MODE : Random (nDOF= 187)(df:7.812)	REF. POINT :	SEQ. : 107 (4-16-92)

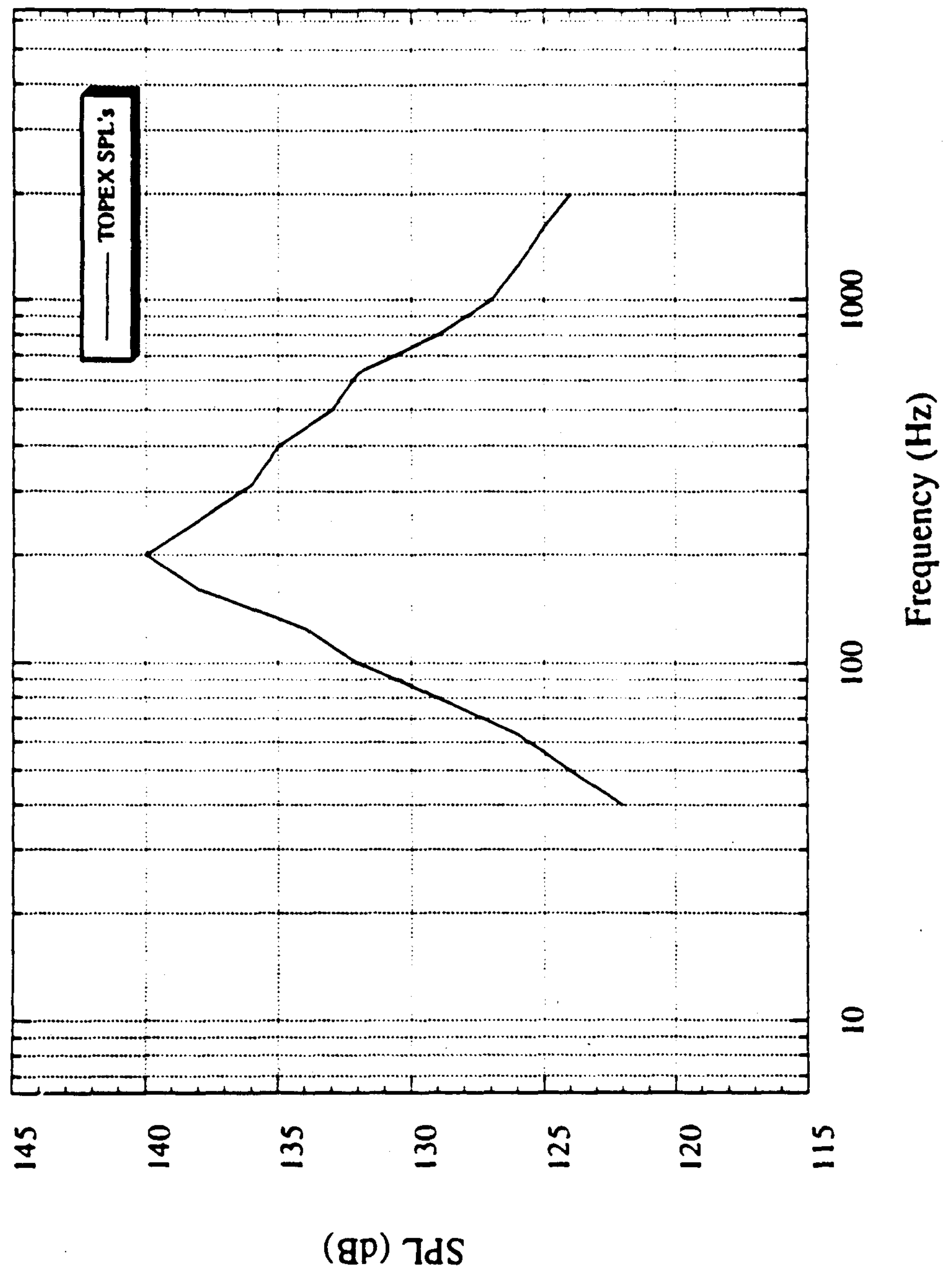
SYMNEX VAP 2000/Analysis

D-11341

122

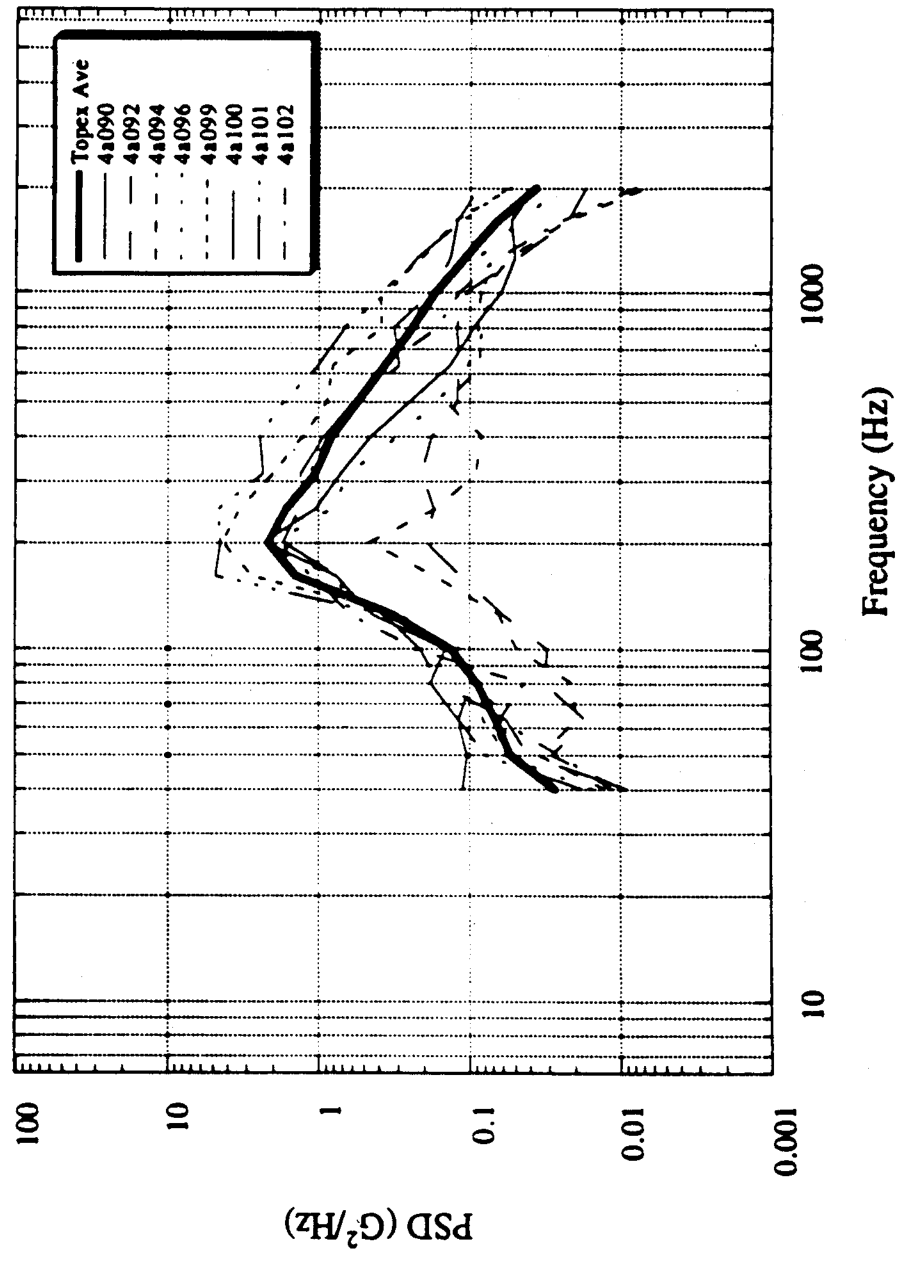
Appendix E:

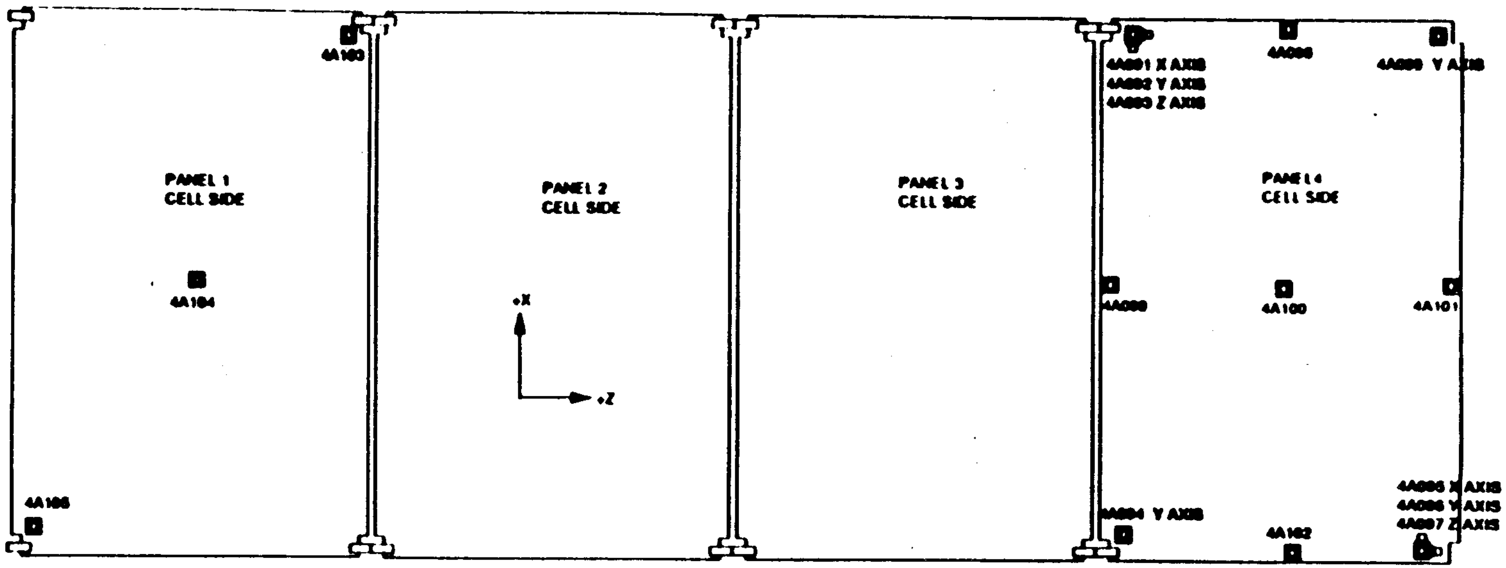
TOPEX Solar Panels
Data from S/C System Acoustic Test



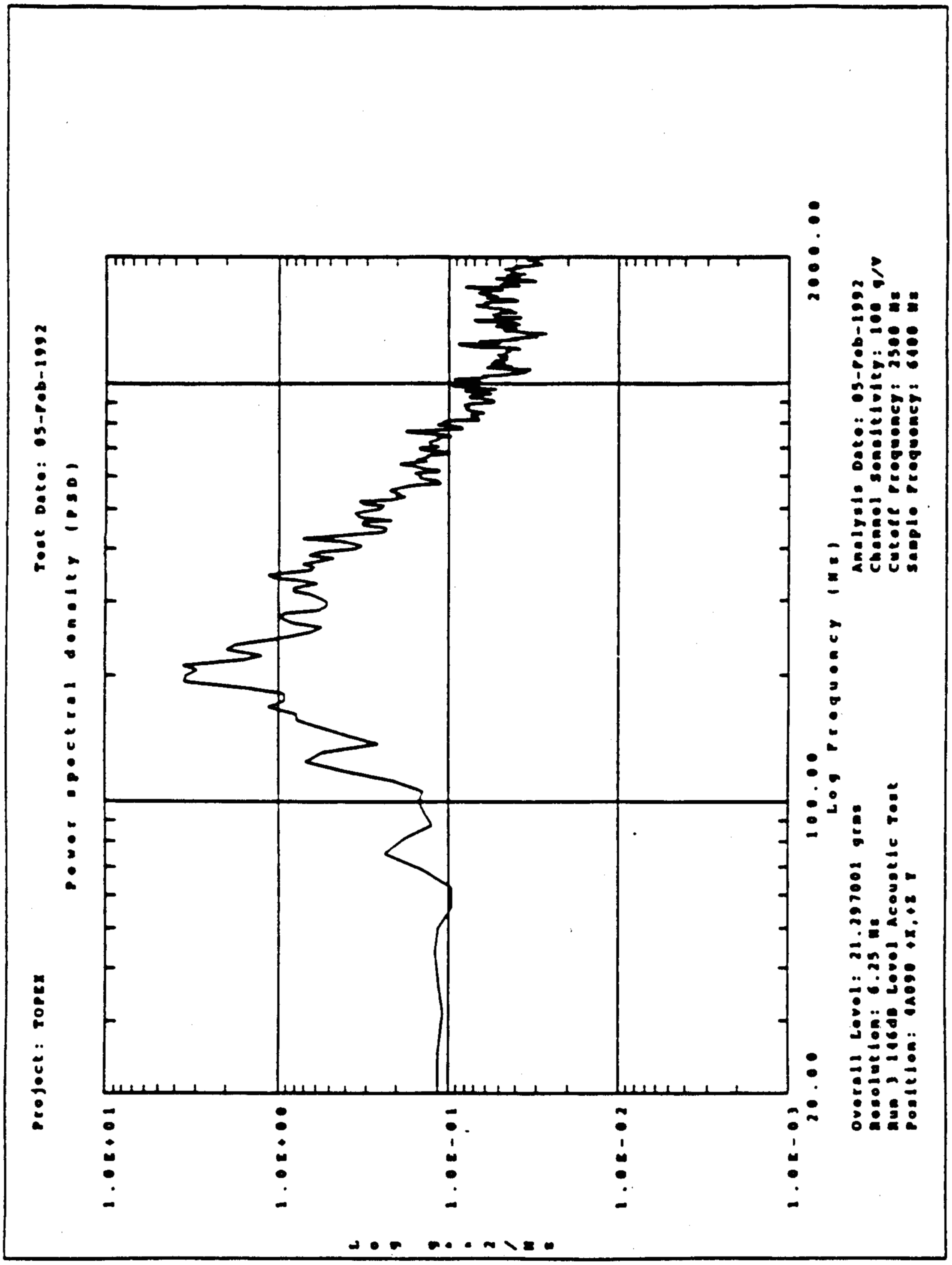
TOPEX S/C System Acoustic Test SPL's

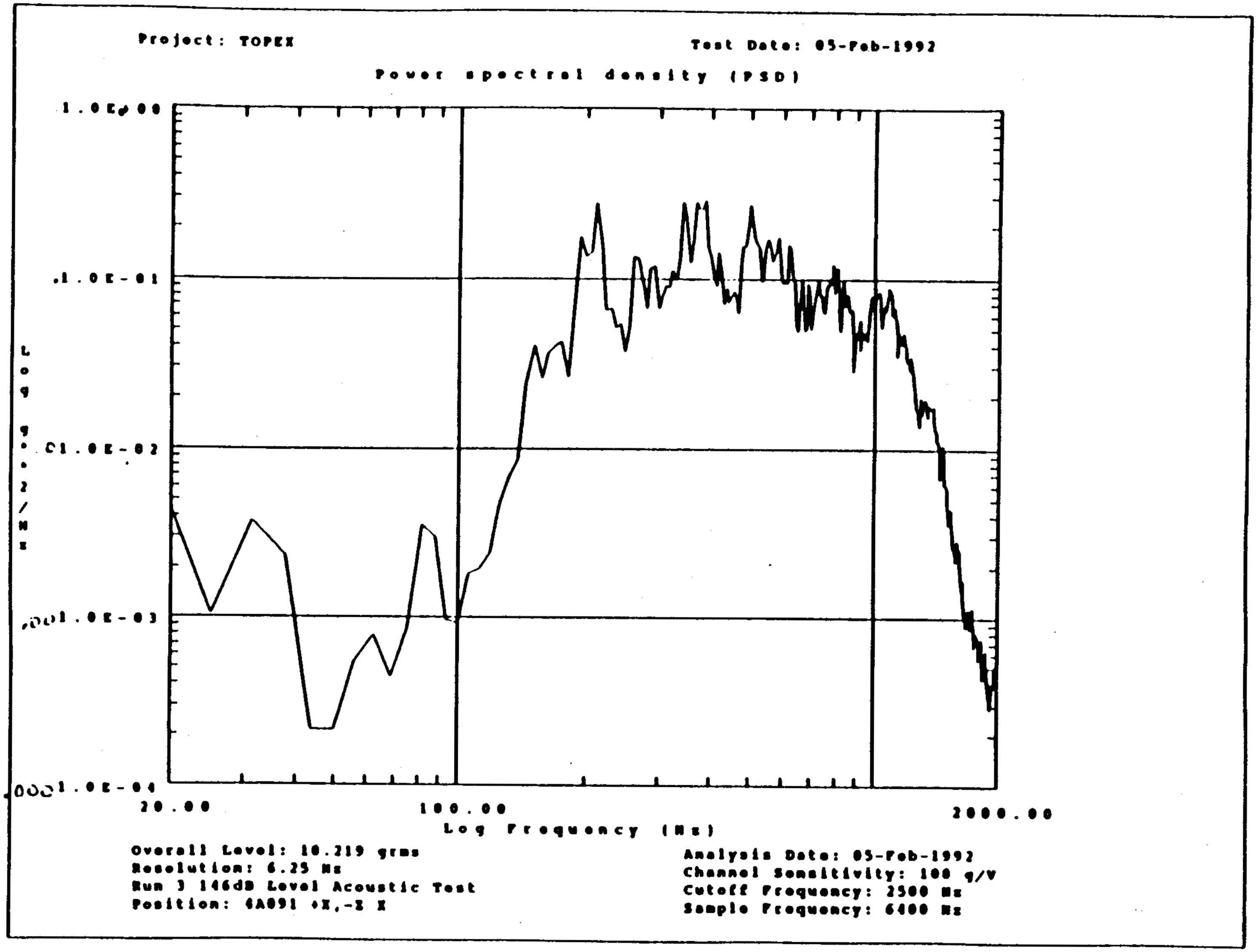
TOPEX System Acoustic Test Data for Solar Panel 4
1/3-Octave Band Data



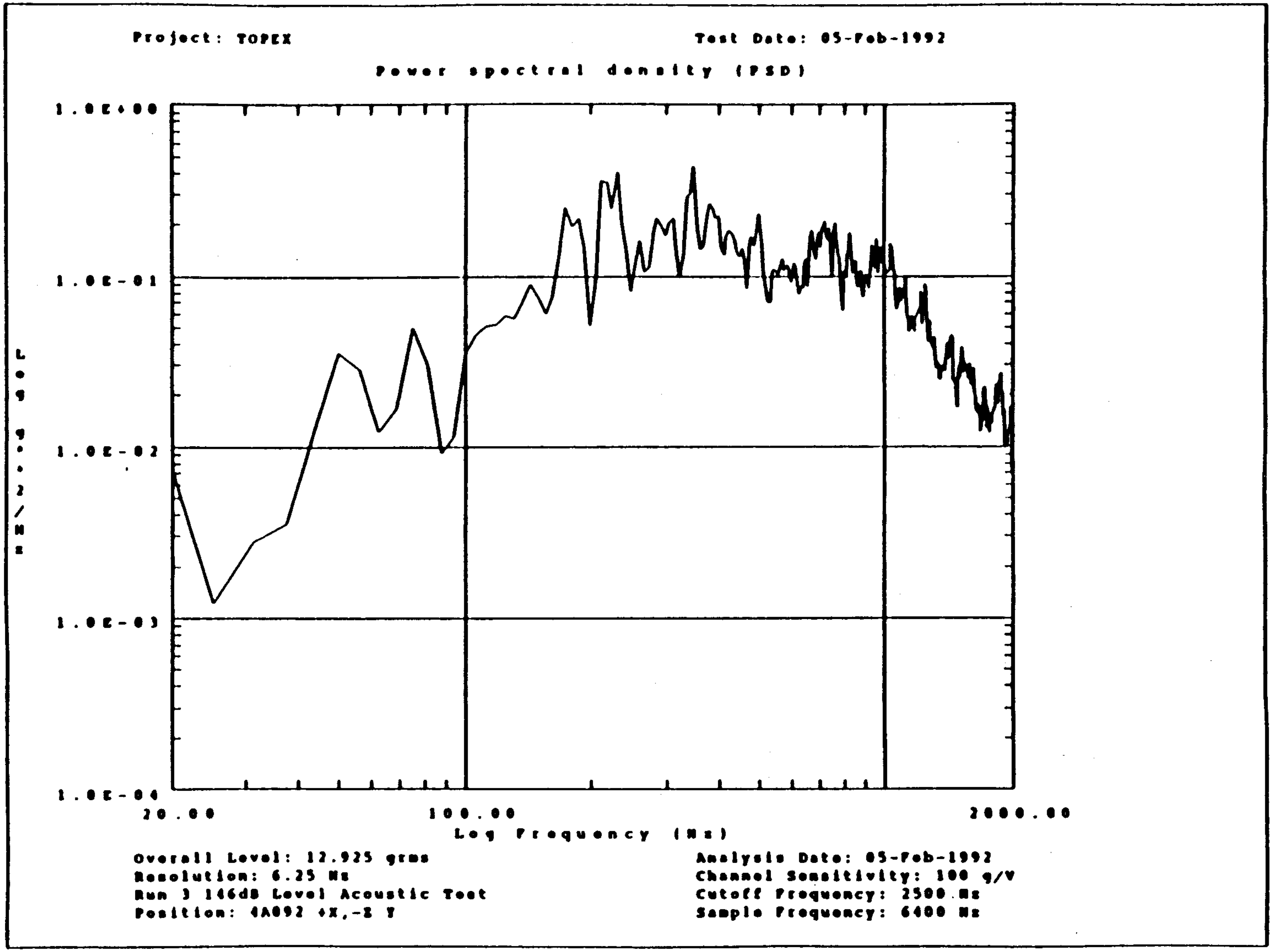


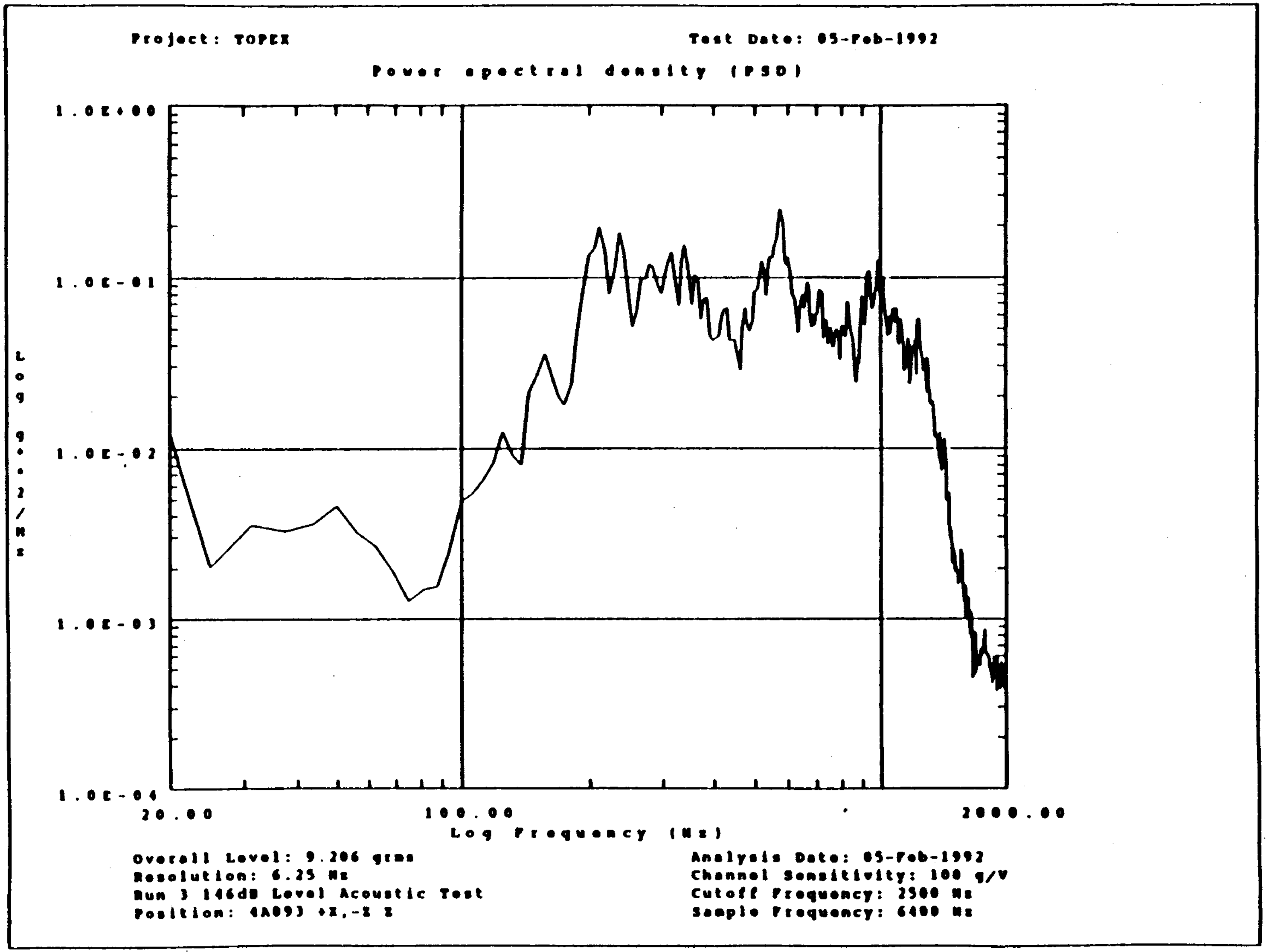
TOPEX Spacecraft Solar Panel - Accelerometer Locations


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 21.297001 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A090 +X,+Z Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz



Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
.1.0E-01
.01.0E-02
.001.0E-03
.0001.0E-04
Log g^2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 10.219 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 6A091 +X,-Z X
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

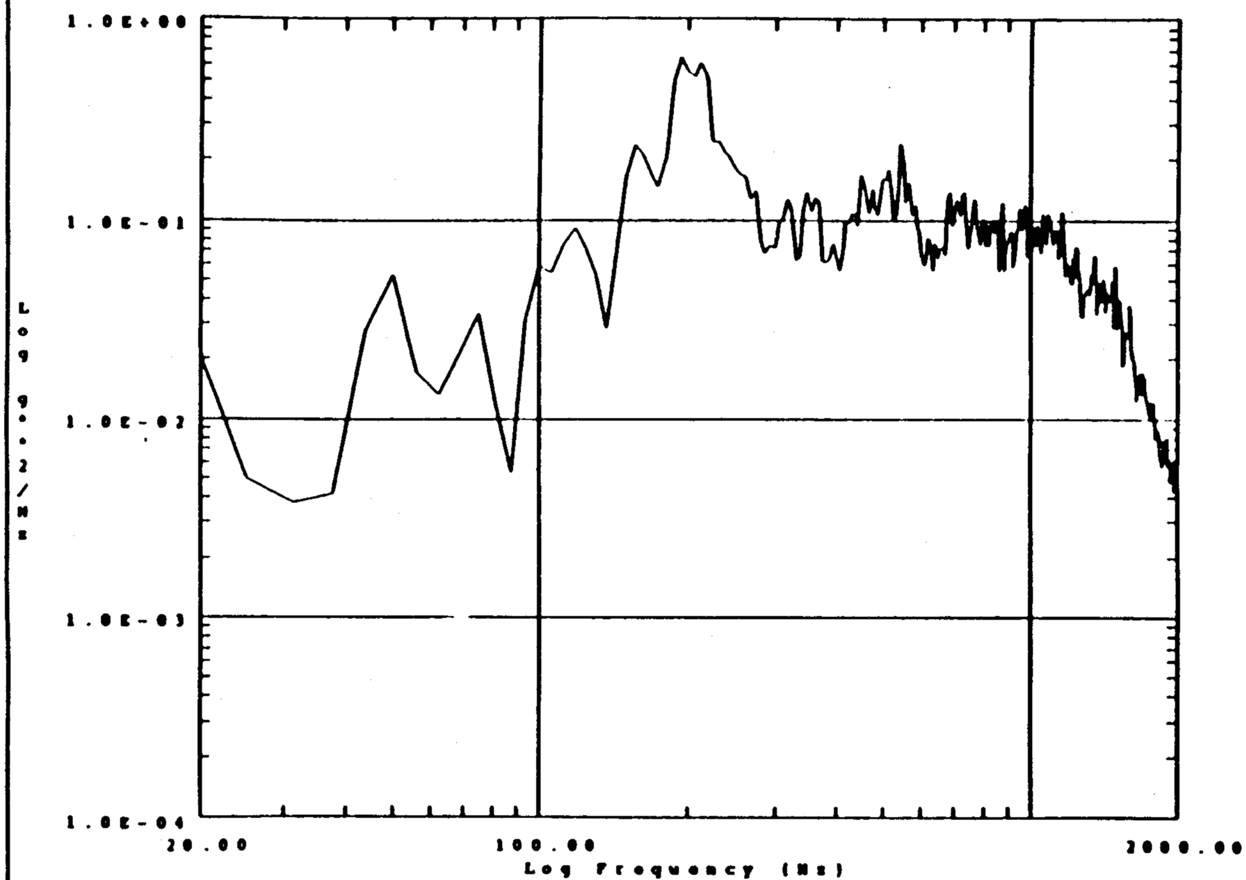

Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 12.925 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A092 +X,-Z Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 9.206 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A093 +X,-Z Z
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

Project: TOPEX

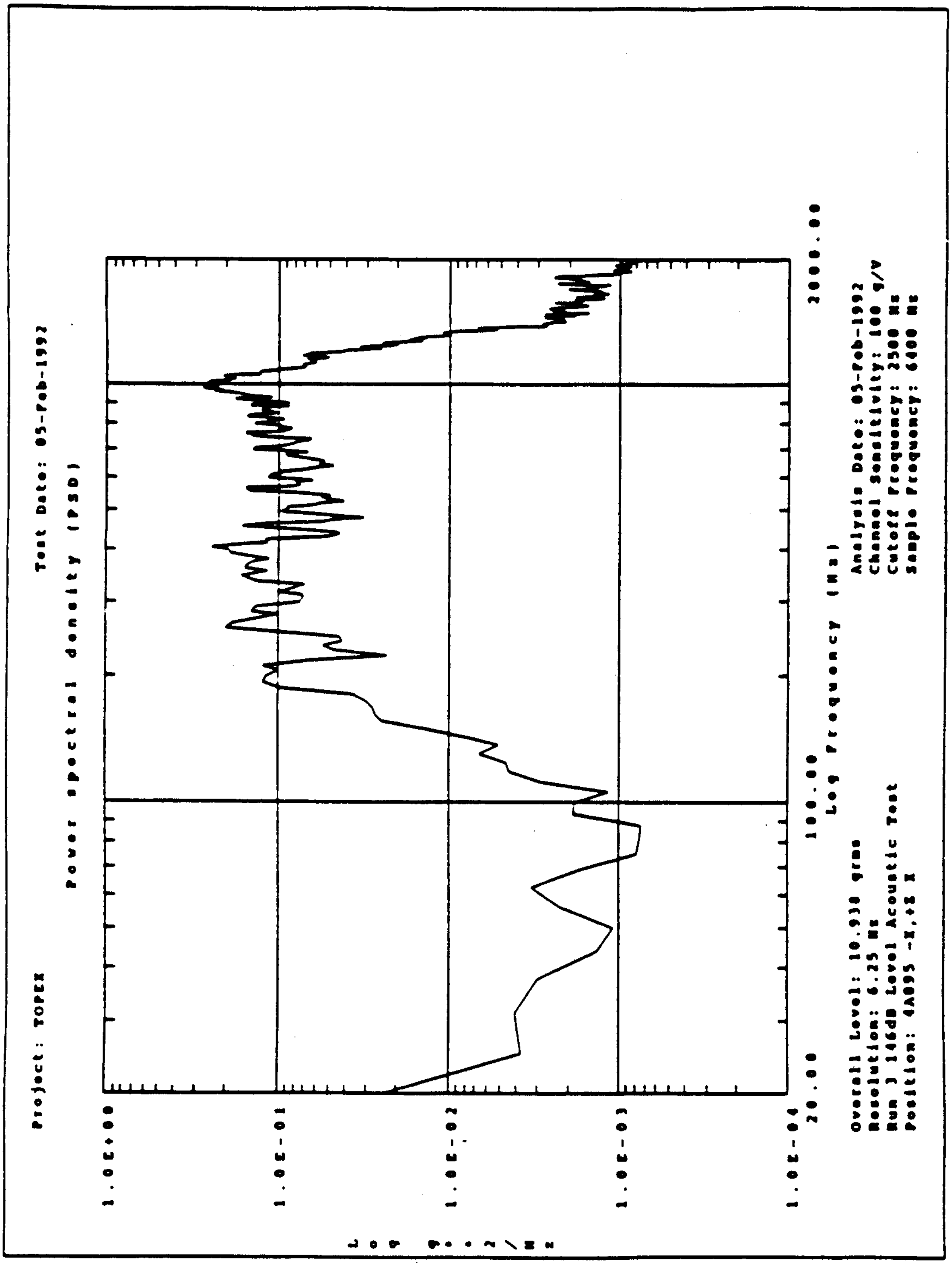
Test Date: 05-Feb-1992

Power spectral density (PSD)

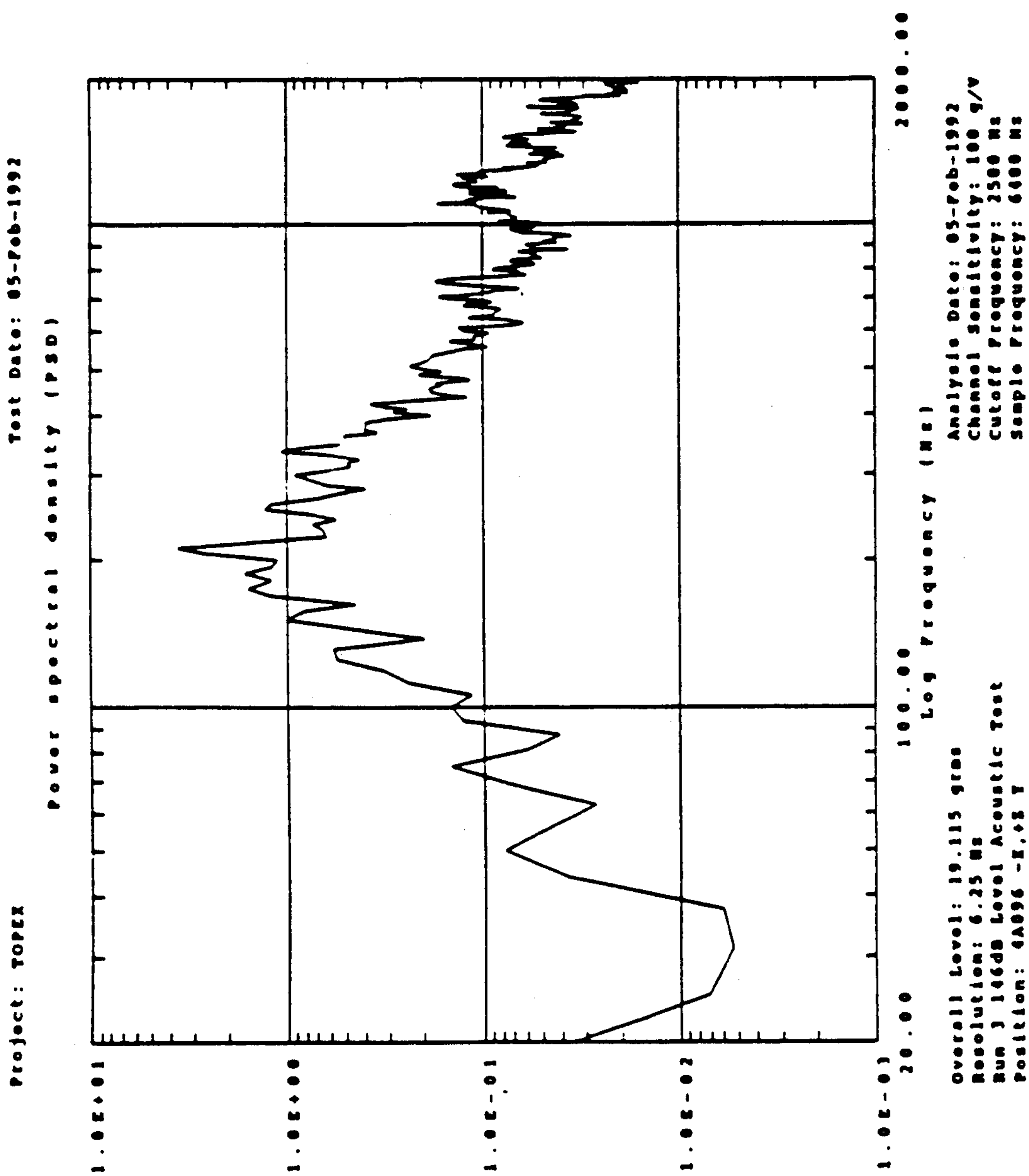


Overall Level: 12.325 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A094 -X,-Z Z

Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

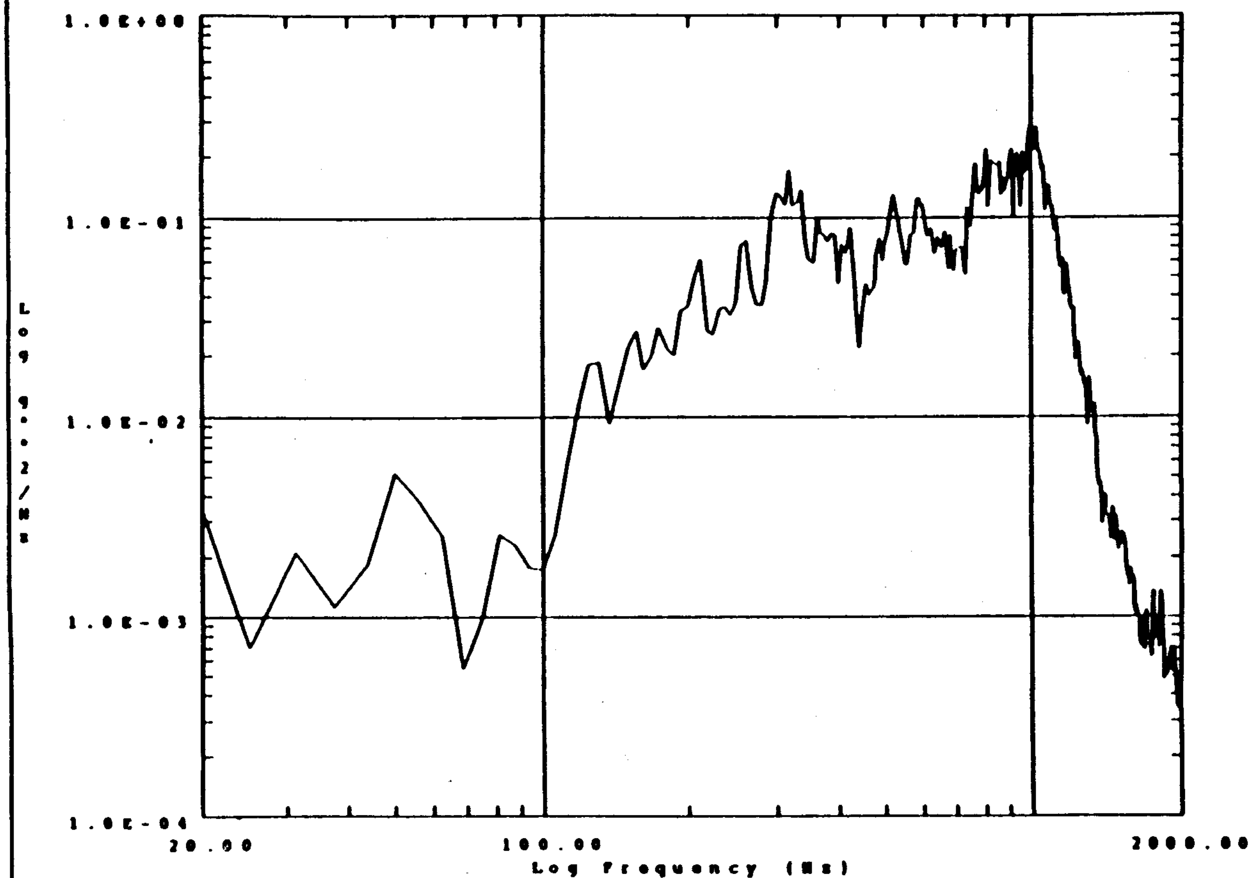


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 10.938 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A095 -X,+Z X
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
Log g^2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 19.115 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A096 -X,+S T
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/v
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

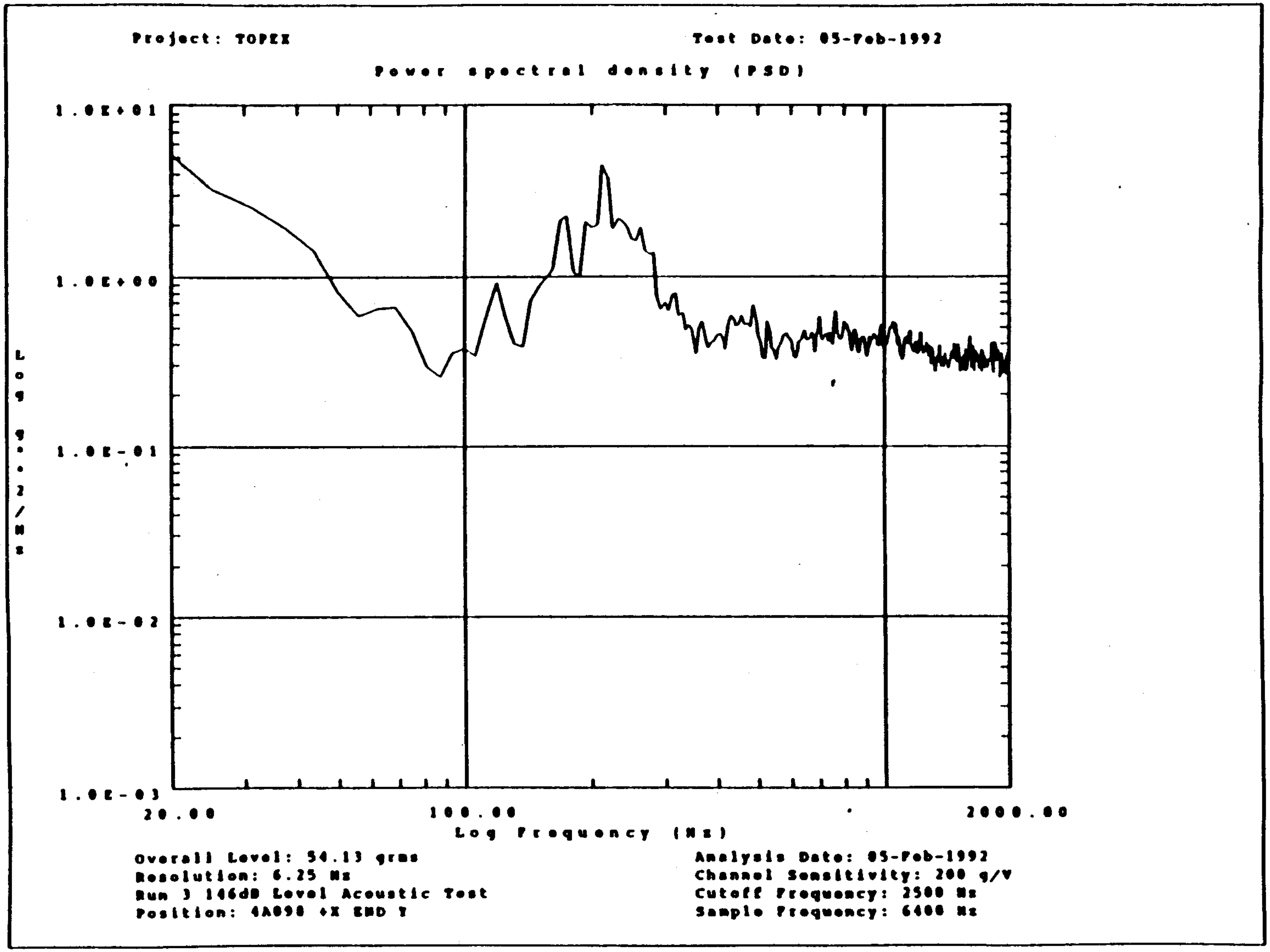
Project: TOPEX Test Date: 05-Feb-1992

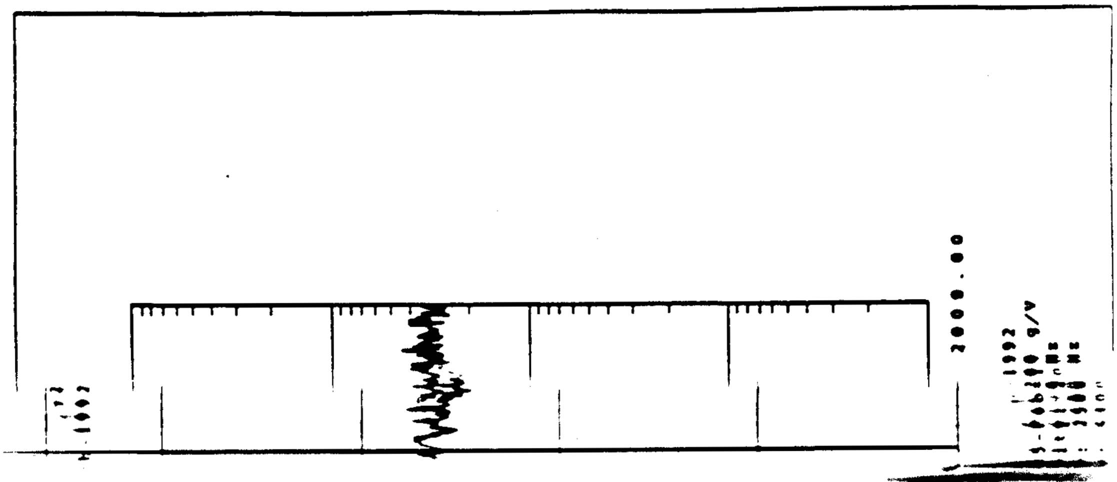
Power spectral density (PSD)

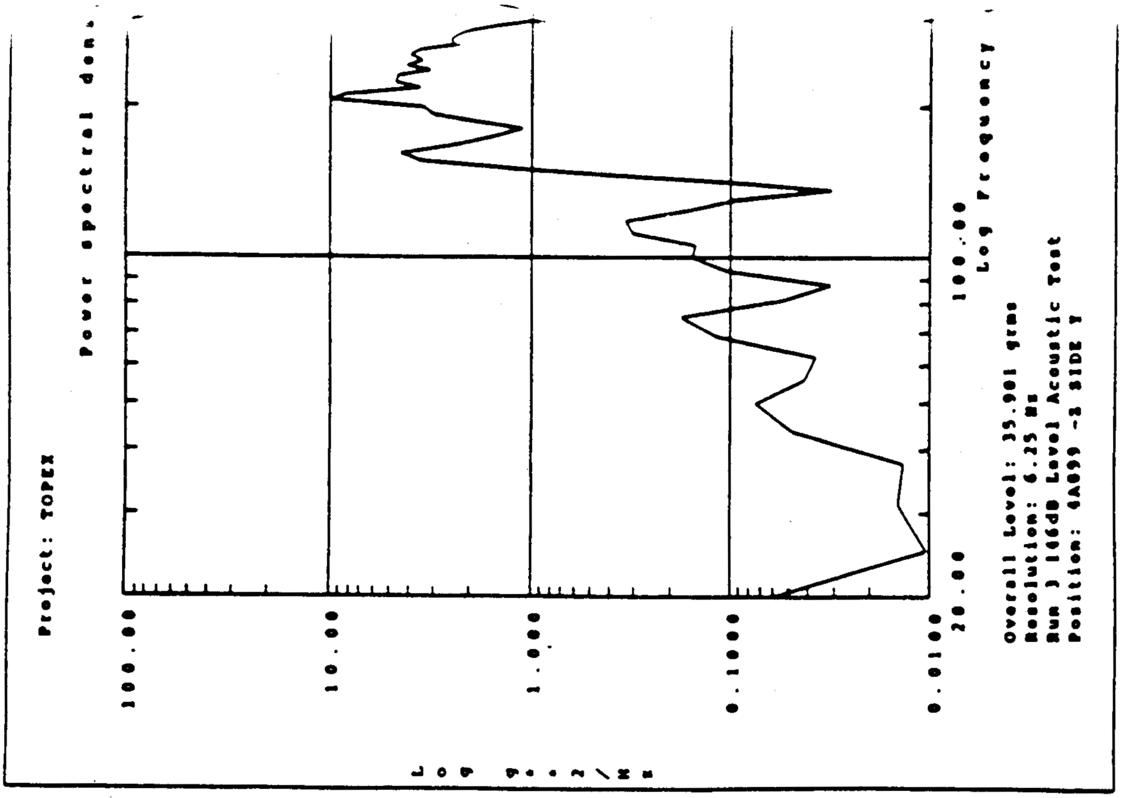


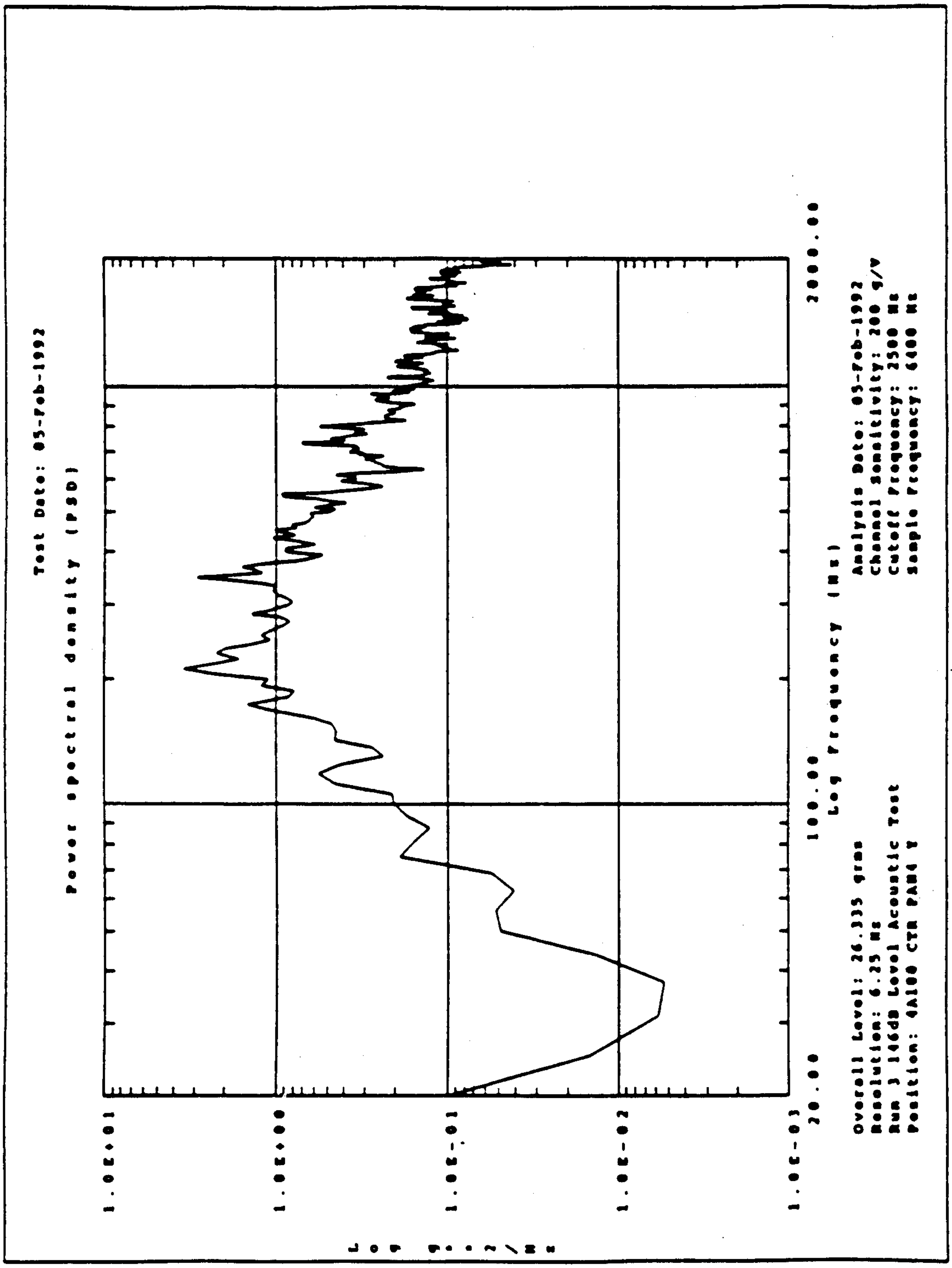
Overall Level: 10.663 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A097 -X,+Z Z

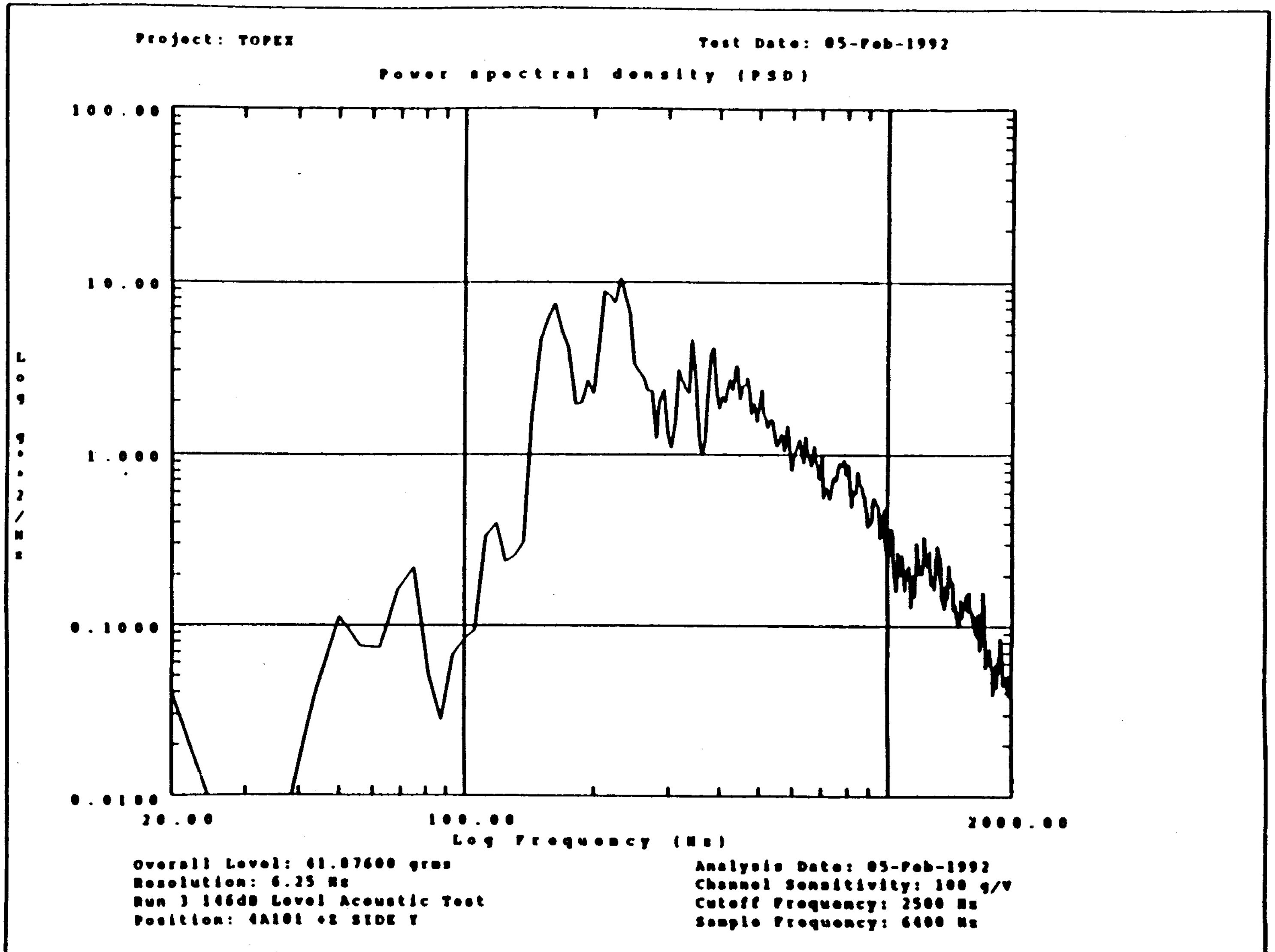
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

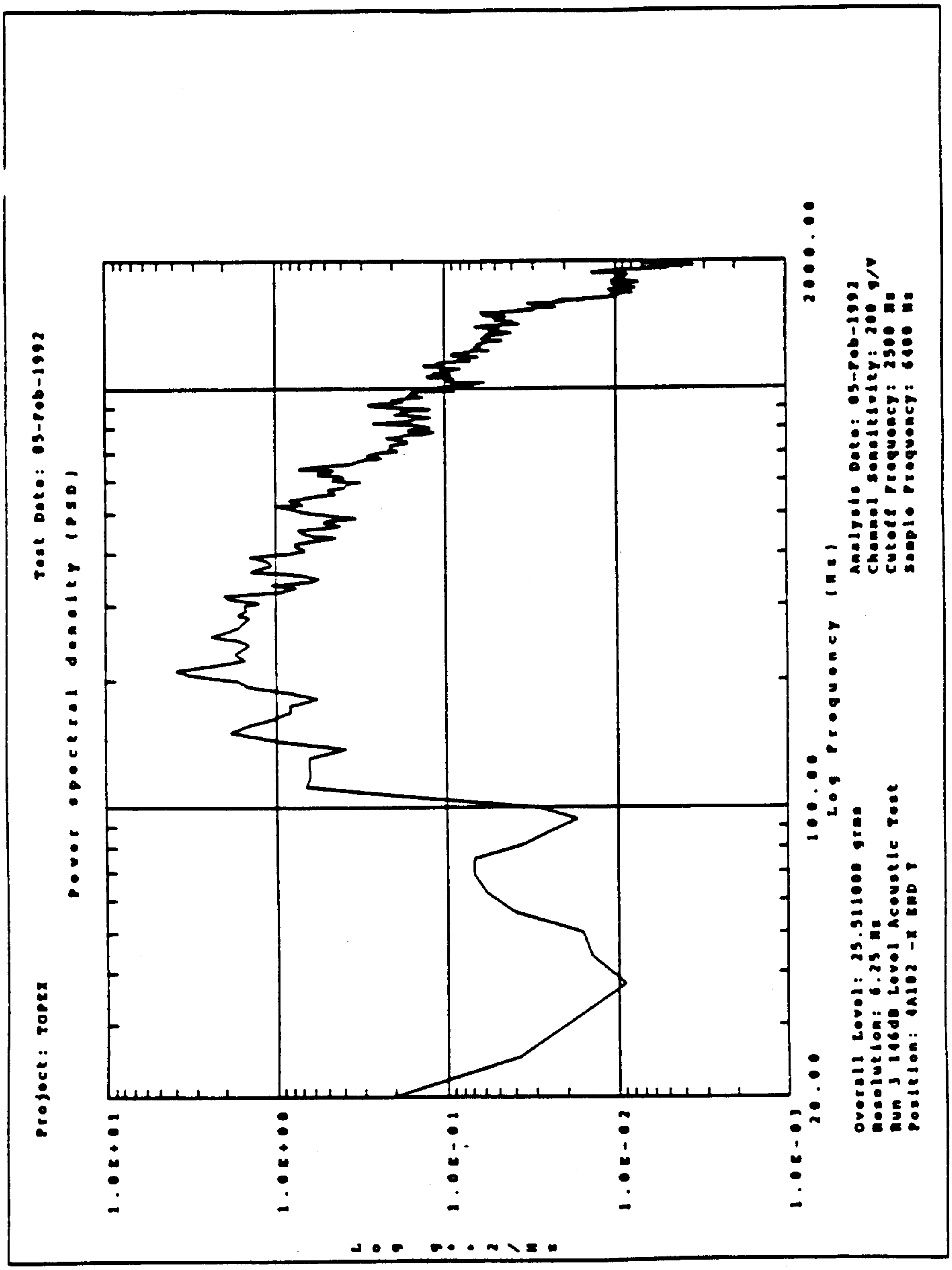

Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 54.13 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A098 +X END Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 200 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

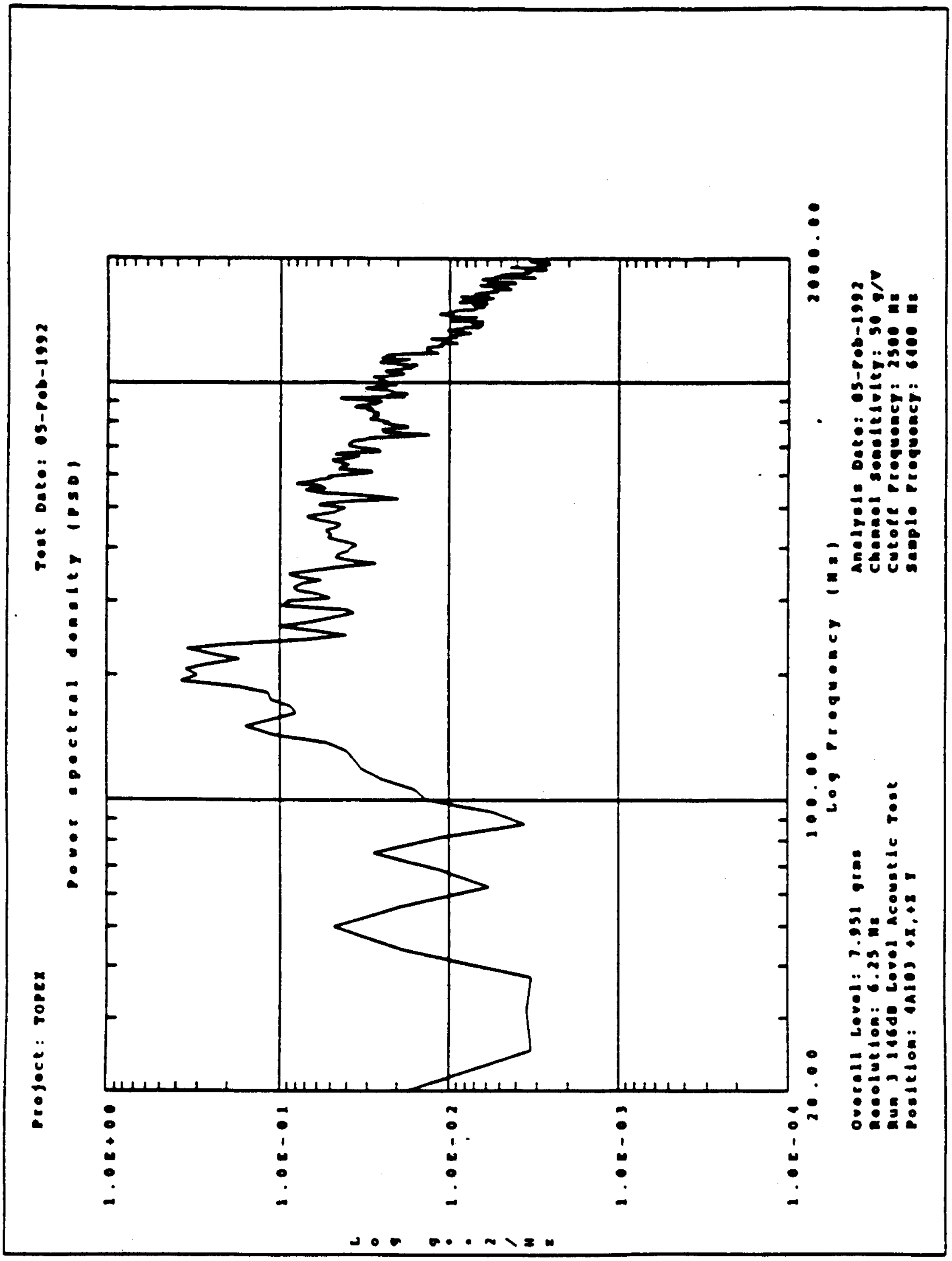

2000.00
1992


Project: TOPEX
Power spectral dens
Log G**2/Hz
100.00
10.00
1.000
0.1000
0.0100
20.00
100.00
Log Frequency
Overall Level: 35.901 grms
Resolution: 6.25 Hz
Run 3 166dB Level Acoustic Test
Position: 4A099 -Z SIDE Y


Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
Log g^2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 26.335 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A100 CTR PAN4 Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 200 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
100.00
10.00
1.000
0.1000
0.0100
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 41.07600 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A101 +Z SIDE Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 100 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

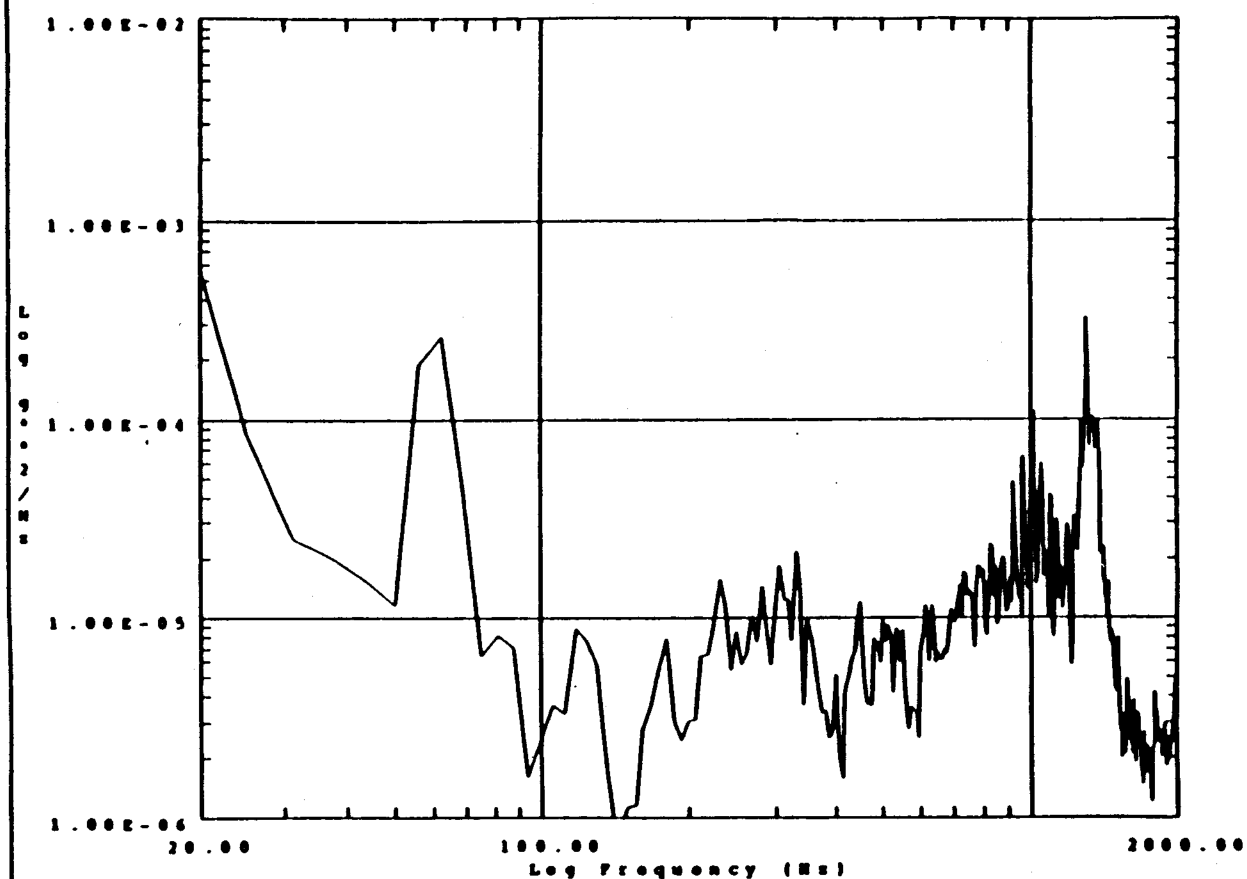

Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 25.511000 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A102 -X END Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 200 g/v
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz



Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Log g**2/Hz
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 7.951 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A103 +X,+Z Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 50 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

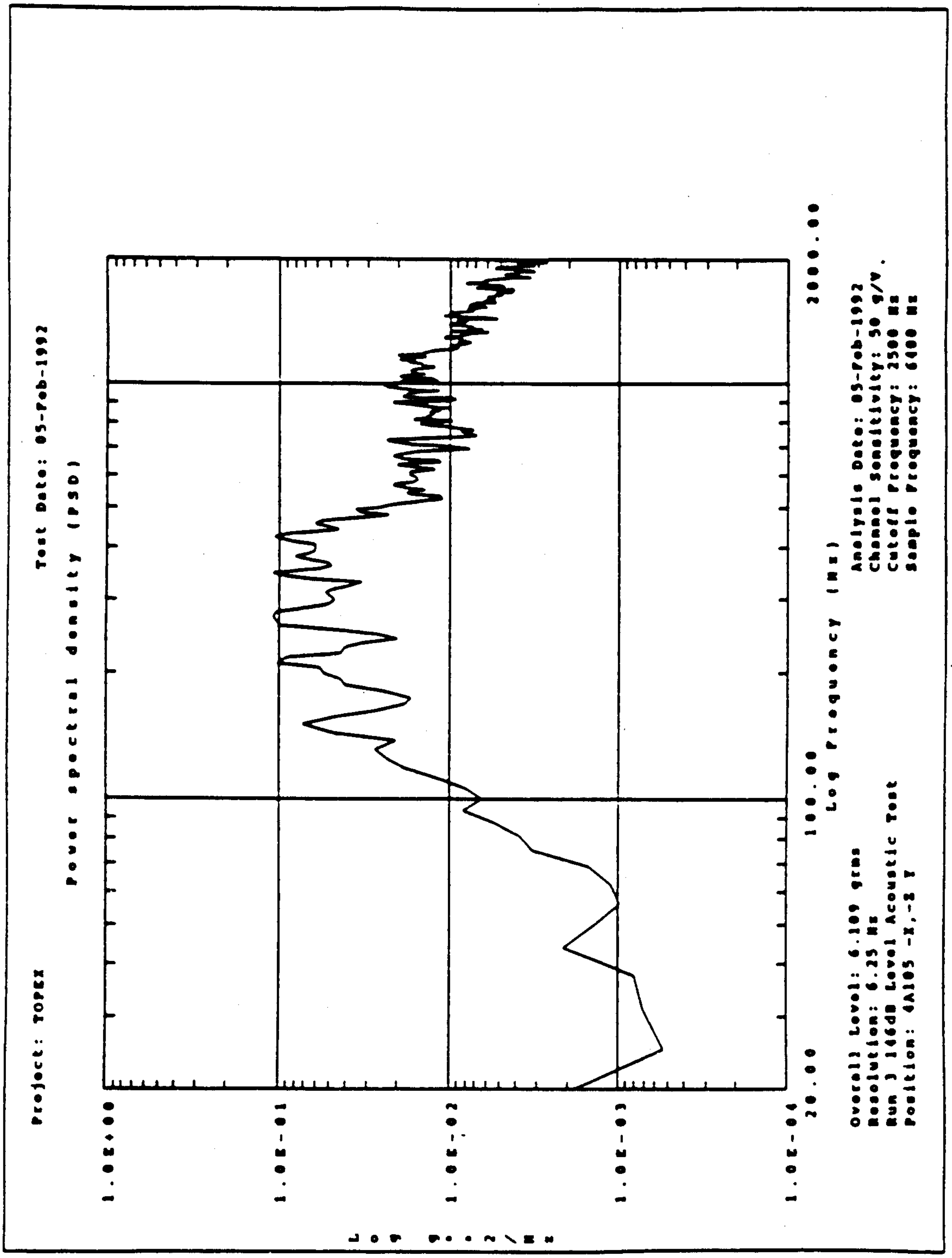
Project: TOPEX Test Date: 05-Feb-1992

Power spectral density (PSD)



Overall Level: 0.234 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A104 CTR PAN Y

Analysis Date: 05-Feb-1992
Channel Sensitivity: 50 g/V
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz


Project: TOPEX
Test Date: 05-Feb-1992
Power spectral density (PSD)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
20.00
100.00
2000.00
Log Frequency (Hz)
Overall Level: 6.109 grms
Resolution: 6.25 Hz
Run 3 146dB Level Acoustic Test
Position: 4A105 -X,-Z Y
Analysis Date: 05-Feb-1992
Channel Sensitivity: 50 g/V.
Cutoff Frequency: 2500 Hz
Sample Frequency: 6400 Hz

Appendix F:

. VAPEPS Panel Model
(Input and Output Runstreams)

EQPL Input File

```
RUN=EQPL 1,SPNL
NS=5,NBL=4,NBW=0.,RLEN=49.1,WID=49.6
list
done
****Bare Skin Layers*****
* AL facesheet
H=0.012,CEN=-0.256
done
* AL Honeycomb Core
H=0.5,CEN=0.,RHO=3.204E-6,E=3.0E4
done
* AL facesheet
H=0.012,CEN=0.256
done
* Missing mass added in thin layer (Adhesive)
H=0.001,CEN=.2505,RHO=.80E-3,E=100.0
done
* Missing mass added in thin layer (Adhesive)
H=0.001,CEN=-.2505,RHO=.80E-3,E=100.0
done
****Stiffener Layers*****
H=0.025,CEN=-0.2255,W=3.35
list
done
H=0.012,CEN=-0.244,W=5.10
list
done
H=0.012,CEN=0.232,W=3.35
list
done
H=0.012,CEN=0.244,W=5.10
```

EQPL Output File

```
                          VAPEPS
  (VibroAcoustic Payload Environment Prediction System)
                       Version 5.5

                   System SUN Computer
                   (Revised May 1992)

                      Developed by
              LOCKHEED MISSILES & SPACE COMPANY

                       Updates by
                JET PROPULSION LABORATORY

                      Sponsored by
                NASA LEWIS RESEARCH CENTER

                     User support by
                JET PROPULSION LABORATORY

    Date:  Thursday, April 29, 1993        Time:   3:34:17 PM.
      Execution mode:  Batch         Core Size:  20000 words

 RD-----------------------------------------------------------------------5.5

V5.5 ? RUN=EQPL 1,SPNL
General parameters >NS=5,NBL=4,NBW=0.,RLEN=49.1,WID=49.6
General parameters >list

NS       =          5 NBL      =          4 NBW      =          0
RLEN     = 4.910E+01 WID       = 4.960E+01 ER        = 1.060E+07 RHOR     = 2.591E-04
CL       = 2.010E+05
General parameters >done
OK
Bare skin layer  1 of  5 >H=0.012,CEN=-0.256
Bare skin layer  1 of  5 >done
OK
Bare skin layer  2 of  5 >H=0.5,CEN=0.,RHO=3.204E-6,E=3.0E4
Bare skin layer  2 of  5 >done
OK
Bare skin layer  3 of  5 >H=0.012,CEN=0.256
Bare skin layer  3 of  5 >done
OK
Bare skin layer  4 of  5 >H=0.001,CEN=.2505,RHO=.80E-3,E=100.0
Bare skin layer  4 of  5 >done
OK
Bare skin layer  5 of  5 >H=0.001,CEN=-.2505,RHO=.80E-3,E=100.0
Bare skin layer  5 of  5 >done
OK
Lengthwise beam layer  1 of  4 >H=0.025,CEN=-0.2255,W=3.35
Lengthwise beam layer  1 of  4 >list
```

```
H        = 2.500E-02 CEN      =-2.255E-01 E        = 1.060E+07 RHO      = 2.591E-04
W        = 3.350E+00
Lengthwise beam layer  1 of  4 >done
OK
Lengthwise beam layer  2 of  4 >H=0.012,CEN=-0.244,W=5.10
Lengthwise beam layer  2 of  4 >list

H        = 1.200E-02 CEN      =-2.440E-01 E        = 1.060E+07 RHO      = 2.591E-04
W        = 5.100E+00
Lengthwise beam layer  2 of  4 >done
OK
Lengthwise beam layer  3 of  4 >H=0.012,CEN=0.232,W=3.35
Lengthwise beam layer  3 of  4 >list

H        = 1.200E-02 CEN      = 2.320E-01 E        = 1.060E+07 RHO      = 2.591E-04
W        = 3.350E+00
Lengthwise beam layer  3 of  4 >done
OK
Lengthwise beam layer  4 of  4 >H=0.012,CEN=0.244,W=5.10
OK
*  Result:  1,EQPL,SPNL   Size: (9 x 1)
*  Result:  1,SEQP,SPNL   Size: (6 x 1)
```

Input Specifications

RLEN= 4.910E+01, WID= 4.960E+01, CL= 2.010E+05

Layer	H	CEN	E	RHO	W
		bare skin			
1	1.200E-02	-2.560E-01	1.060E+07	2.591E-04	N/A
2	5.000E-01	0.000E+00	3.000E+04	3.204E-06	N/A
3	1.200E-02	2.560E-01	1.060E+07	2.591E-04	N/A
4	1.000E-03	2.505E-01	1.000E+02	8.000E-04	N/A
5	1.000E-03	-2.505E-01	1.000E+02	8.000E-04	N/A
		lengthwise beams			
1	2.500E-02	-2.255E-01	1.060E+07	2.591E-04	3.350E+00
2	1.200E-02	-2.440E-01	1.060E+07	2.591E-04	5.100E+00
3	1.200E-02	2.320E-01	1.060E+07	2.591E-04	3.350E+00
4	1.200E-02	2.440E-01	1.060E+07	2.591E-04	5.100E+00

Equivalent Parameters

H= 7.009E-01, E= 6.179E+05, RHO= 1.528E-05, RHOS= 9.420E-06

Stress prediction parameters

H= 2.718E-01, E= 1.060E+07, RHO= 3.466E-05, RHOS= 9.420E-06

Centroid distance = -6.343E-03

*** Normal termination. Ciau! ***

SEMOD Input File

```
SEMOD 1,QPNL
ELNAME
EXTA,1
RHO=1.17E-7,CO=1.306E4,VOLUME=1.728E7,AP=4.13E5,AAC=0.01
DESC='EXTERNAL ACOUSTIC SPACE 1'
DONE
PANEL,3
H=0.7009,E=6.179E5,RHO=2.448E-5,RHOS=1.716E-5,CL=2.01E5,AP=2.435E3
ALX=49.1,ALY=49.6,DLF=-0.01,PATA=0,ASMS=0.0,PIVOTFRQ=500.
DESC='MAGELLAN SOLAR ARRAY'
DONE
DONE
PATHNAME
EXTA,PANEL,49
DONE
DONE
FREQUENCY 25.0 2500.0
SETEXEC,EXTA
EXCITATION
129.2,131.2,133.0,134.1,135.0,135.5,135.5,135.5,134.8,134.3,133.9,136.5
132.8,131.1,129.7,128.0,126.5,125.0,123.0,121.5,120.0
MDENS
ATACALC 1
ATACO
CFAC 7,1,4
TPRD
POWER
LIST ATA,CRIT,DENS,RESP
DONE
RUN=GETR 1,QPNL 1,TRSP,QPNL 1
PANEL
RUN=TPVL 1,TRSP,QPNL 1,QPNL 0.95
PRIND 1,TPVL,QPNL
```

SEMOD Output File

```
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 Date:  Saturday, May 22, 1993        Time:   3:40:08 PM.
  Execution mode:  Batch        Core Size:  20000 words

RD----------------------------------------------------------------------5.5

V5.5 ? SEMOD 1,QPNL
Creating new model QPNL

SEMOD > ELNAME
Maximum number of elements    =    50
Maximum variable storage      =   900
Maximum string storage words =  1000
Input element name > EXTA,1
EXTA > RHO=1.17E-7,CO=1.306E4,VOLUME=1.728E7,AP=4.13E5,AAC=0.01
EXTA > DESC='EXTERNAL ACOUSTIC SPACE 1'
EXTA > DONE
OK
Input element name > PANEL,3
PANEL > H=0.7009,E=6.179E5,RHO=2.448E-5,RHOS=1.716E-5,CL=2.01E5,AP=2.435E3
PANEL > ALX=49.1,ALY=49.6,DLF=-0.01,PATA=0,ASMS=0.0,PIVOTFRQ=500.
PANEL > DESC='MAGELLAN SOLAR ARRAY'
PANEL > DONE
OK
Input element name > DONE
OK
SEMOD > PATHNAME
Approximate maximum number of connections =    20
Approximate maximum variable storage      =   100
Input connection > EXTA,PANEL,49
Creating new path.
EXTA,PANEL > DONE
OK
Input connection > DONE
```

```
OK
SEMOD > FREQUENCY 25.0 2500.0
  FREQ  1:    FREQ   QPNL    0     0, SIZE =     21      1, NJ =     1
SEMOD > SETEXEC,EXTA
SEMOD > EXCITATION
EXTA  (21) >129.2,131.2,133.0,134.1,135.0,135.5,135.5,135.5,134.8,134.3,133.9,
EXTA  ( 9) > 136.5,132.8,131.1,129.7,128.0,126.5,125.0,123.0,121.5,120.0
SEMOD > MDENS
  DENS  1:    DENS   QPNL    0     0, SIZE =     21      2, NJ =     1
SEMOD > ATACALC 1
# of damping loss factors  =   2
# of coupling loss factors =   2
Element =   1 Type =   1
Element =   2 Type =   3
   1Path type =  49Path code = 001002
  ATA   1:    ATA    QPNL    0     0, SIZE =     21      4, NJ =     1
SEMOD > ATACO
  CO    1:    CO     QPNL    0     0, SIZE =      4     21, NJ =     1
  TRNF  1:    TRNF   QPNL    0     0, SIZE =     21      1, NJ =     1
SEMOD > CFAC 7,1,4
  CONV  1:    CONV   QPNL    0     0, SIZE =     21      2, NJ =     1
SEMOD > TPRD
  RESP  1:    RESP   QPNL    0     0, SIZE =     21      2, NJ =     1
SEMOD > POWER
  POWR  1:    POWR   QPNL    0     0, SIZE =     21      4, NJ =     1
  PCRF  1:    PCRF   QPNL    0     0, SIZE =     21      3, NJ =     1
SEMOD > LIST ATA,CRIT,DENS,RESP
```

1Damping and coupling loss factors for model QPNL

Frequency	EXTA	PANEL	EXTA	PANEL
Hertz	EXTA	PANEL	PANEL	EXTA
25.0	4.9684E-03	1.0000E-02	3.9077E-04	7.9528E-04
31.5	3.9432E-03	1.0000E-02	3.1014E-04	1.0021E-03
40.0	3.1053E-03	1.0000E-02	2.4423E-04	1.2724E-03
50.0	2.4842E-03	1.0000E-02	1.9539E-04	1.5906E-03
63.0	1.9716E-03	1.0000E-02	1.5507E-04	2.0041E-03
80.0	1.5526E-03	1.0000E-02	1.2212E-04	2.5449E-03
100.0	1.2421E-03	1.0000E-02	9.7693E-05	3.1811E-03
125.0	9.9368E-04	1.0000E-02	7.8154E-05	3.9764E-03
160.0	7.7631E-04	1.0000E-02	6.1058E-05	5.0898E-03
200.0	6.2105E-04	1.0000E-02	4.8846E-05	6.3622E-03
250.0	4.9684E-04	1.0000E-02	3.9077E-05	7.9528E-03
315.0	3.9432E-04	1.0000E-02	3.1014E-05	1.0021E-02
400.0	3.1053E-04	1.0000E-02	2.4423E-05	1.2724E-02
500.0	2.4842E-04	1.0000E-02	1.9539E-05	1.5906E-02
630.0	1.9716E-04	7.9365E-03	1.5507E-05	2.0041E-02
800.0	1.5526E-04	6.2500E-03	8.5012E-06	1.7717E-02
1000.0	1.2421E-04	5.0000E-03	4.3526E-06	1.4173E-02
1250.0	9.9368E-05	4.0000E-03	2.2285E-06	1.1339E-02
1600.0	7.7631E-05	3.1250E-03	1.0627E-06	8.8583E-03
2000.0	6.2105E-05	2.5000E-03	5.4408E-07	7.0866E-03
2500.0	4.9684E-05	2.0000E-03	2.7857E-07	5.6693E-03

1Critcal frequencies for model QPNL

Frequency Hertz	EXTA PANEL
25.0	6.6749E+02
31.5	6.6749E+02
40.0	6.6749E+02
50.0	6.6749E+02
63.0	6.6749E+02
80.0	6.6749E+02
100.0	6.6749E+02
125.0	6.6749E+02
160.0	6.6749E+02
200.0	6.6749E+02
250.0	6.6749E+02
315.0	6.6749E+02
400.0	6.6749E+02
500.0	6.6749E+02
630.0	6.6749E+02
800.0	6.6749E+02
1000.0	6.6749E+02
1250.0	6.6749E+02
1600.0	6.6749E+02
2000.0	6.6749E+02
2500.0	6.6749E+02

1Modal densities for model QPNL

Frequency Hertz	EXTA	PANEL
25.0	6.0926E-02	2.9937E-02
31.5	9.6727E-02	2.9937E-02
40.0	1.5597E-01	2.9937E-02
50.0	2.4371E-01	2.9937E-02
63.0	3.8691E-01	2.9937E-02
80.0	6.2389E-01	2.9937E-02
100.0	9.7482E-01	2.9937E-02
125.0	1.5232E+00	2.9937E-02
160.0	2.4955E+00	2.9937E-02
200.0	3.8993E+00	2.9937E-02
250.0	6.0926E+00	2.9937E-02
315.0	9.6727E+00	2.9937E-02
400.0	1.5597E+01	2.9937E-02
500.0	2.4371E+01	2.9937E-02
630.0	3.8691E+01	2.9937E-02
800.0	6.2389E+01	2.9937E-02
1000.0	9.7482E+01	2.9937E-02
1250.0	1.5232E+02	2.9937E-02
1600.0	2.4955E+02	2.9937E-02
2000.0	3.8993E+02	2.9937E-02
2500.0	6.0926E+02	2.9937E-02

1Excitations and responses for model QPNL

Frequency Hertz	EXTA dB	PANEL G**2/Hz
25.0	129.2	1.5507E+00
31.5	131.2	2.2688E+00
40.0	133.0	3.3599E+00
50.0	134.1	4.5445E+00
63.0	135.0	4.9881E+00
80.0	135.5	5.3689E+00
100.0	135.5	5.5162E+00
125.0	135.5	5.1094E+00
160.0	134.8	3.6090E+00
200.0	134.3	3.3709E+00
250.0	133.9	2.7519E+00
315.0	136.5	4.2246E+00
400.0	132.8	1.5917E+00
500.0	131.1	1.0191E+00
630.0	129.7	6.3161E-01
800.0	128.0	3.4790E-01
1000.0	126.5	2.1271E-01
1250.0	125.0	1.1832E-01
1600.0	123.0	5.2257E-02
2000.0	121.5	3.3632E-02
2500.0	120.0	1.8708E-02

```
SEMOD > DONE
V5.5 ? RUN=GETR 1,QPNL 1,TRSP,QPNL 1
Enter   1 element names.
 >PANEL
*  1,TRSP,QPNL ( 21,  1)
V5.5 ? RUN=TPVL 1,TRSP,QPNL 1,QPNL 0.95
V5.5 ? PRIND 1,TPVL,QPNL
PRIND*1:TPVL/QPNL(1-21,1-1)*
```

R/C	1
1	8.9803E+00
2	1.3139E+01
3	1.9458E+01
4	2.6318E+01
5	2.8886E+01
6	3.1092E+01
7	3.1945E+01
8	2.9589E+01
9	2.0900E+01
10	1.9521E+01
11	1.5936E+01
12	2.4465E+01
13	9.2176E+00
14	5.9014E+00
15	3.6577E+00
16	2.0147E+00
17	1.2318E+00
18	6.8519E-01

```
   19 3.0263E-01
   20 1.9477E-01
   21 1.0834E-01
V5.5 ?

*** Normal termination. Ciau! ***
```